Coordination and Support Action SET4H2

Study on enablers and challenges to scale-up EU-based deployment of H2 to feed the EU Strategy on Energy System Integration and the EU Offshore RES Strategy

D3.5

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Authors: Paulo Partidário, Paulo Martins (DGEG)

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Table of contents

List of tables

List of abbreviations and acronyms

List of abbreviations

AEL	Alkaline Electrolysis
CAPEX	Capital Expenditures
CCUS	Carbon Capture, Use and Storage
CEF	Connecting Europe Facility
CETP	Clean Energy Transition Partnership
CHJU	Clean Hydrogen Partnership
CfD	Contracts for Difference
EC	European Commission
ECH2A	European Clean Hydrogen Alliance
ECHO	European Hydrogen Observatory
EHB	European Hydrogen Backbone
EIGL	Energy and Industry Geography Lab
EV	Electric Vehicle
FID	Final Investment Decision
GW	Gigawatt
H2	Hydrogen
IEA	International Energy Agency
IP	Implementation Plan
IPCEI	Important Projects of Common European Interest
IWG	Implementation Working Group
JRC	Joint Research Centre
KPI	Key Performance Indicator
LCOE	Levelized Cost of Electricity
LCOH	Levelized Cost of Hydrogen
LNG	Liquefied Natural Gas
MS	Member State
MSP	Maritime Spatial Planning
Mt	Million tonnes
NZIA	Net-Zero Industry Act
OH2P	Offshore Hydrogen Production
OPEX	Operational Expenditures
ORES	Offshore Renewable Energy Systems
P2X	Power-to-X
PEM	Proton Exchange Membrane Electrolysis
PFAS	Per- and polyfluoroalkyl substances
PPA	Power Purchase Agreements
RED III	Renewable Energy Directive
RFNBO	Renewable Fuels of non-biological Origin
R&D	Research and Development
R&I	Research and Innovation
SET Plan	European Strategic Energy Technology Plan
TEN-E	Trans-European Networks for Energy
TPC (IEA Hydrogen)	Technology Collaboration Programme
TRL	Technology Readiness Level

List of acronyms

Acronyms of CSA SET4H2 consortium partners

AEA: Österreichische Energieagentur - Austrian Energy Agency

BGH2A: Balgarska Asotsiatsia za Vodorod, Gorivni Kletki I Sahranenie na Energia (Bulgarian Hydrogen, Fuel Cell and Energy Storage Association)

EUREC: Association of European Renewable Energy Research Centers

DGEG: Direção-Geral de Energia e Geologia (Directorate General for Energy and Geology)

DLR: Deutsches Zentrum für Luft- und Raumfahrt e.V.

HER: Hydrogen Europe Research

MUR: Ministero dell'Università e della Ricerca

UNIBO: Alma Mater Studiorum – Università di Bologna

Executive Summary

The SET4H2 D3.5 report aims to provide a comprehensive analysis of the strategic role of hydrogen (H_2) in the EU's energy transition. It takes a particular focus in the context of the EU Strategy for Energy System Integration and of the EU Strategy on Offshore Renewable Energy, with a view to assist a discussion on the building-up of the SET Plan H2 IWG. Adding to that, the recent findings of EC.SWD (2025) 121 final "Report on implementation and monitoring of large-scale hydrogen deployment projects: the IPCEIs on hydrogen and the ECH2A project pipeline", were integrated in such discussion, thus covering the current policy framework, technological landscapes, and both implementation challenges, and opportunities. That enabled to produce recommendations addressing the SET Plan on hydrogen deployment strategies across Europe.

Key findings were the following:

- Hydrogen is central to decarbonizing hard-to-electrify sectors such as heavy industry, maritime transport, and aviation.
- The EU's strategies emphasize renewable hydrogen production via electrolysis, supported by offshore wind and other renewable sources.
- Despite ambitious targets, implementation gaps persist due to high costs, infrastructure delays, regulatory fragmentation, and market uncertainty.
- Lessons from EU and global hydrogen projects (e.g., IPCEIs, ECH2A, IEA data) reveal systemic issues in project execution, funding, and market creation.
- The Implementation Working Group (IWG) Hydrogen Implementation Plan requires a more holistic approach, a clear focus on interdependencies across the hydrogen value chain, a modularity dimension to guide national/local adaptations or scalability, and mechanisms to address real-world deployment challenges, in particular due to the lessons learnt with the EC key findings on the SWD(2025) 121 final.

Strategic recommendations

- Strengthen Policy and Regulatory Frameworks:
    - Accelerate permitting processes and harmonize hydrogen-specific regulations.
    - Introduce market-shaping tools like Contracts for Difference (CfDs) and demand-side quotas.
- Enhance Infrastructure Planning:
    - Develop binding milestones for hydrogen transport and storage infrastructure.
    - Integrate hydrogen planning with electricity and gas grids.
- Improve Funding and Investment Coordination:
    - Align EU and national funding windows.
    - Utilize instruments like the European Hydrogen Bank for de-risking.
- Focus on Implementation Readiness:
    - Prioritize projects with signed Final Investment Decisions (FIDs) and offtake agreements.
    - Introduce performance dashboards and KPIs to monitor progress.
- Promote Sectoral Prioritization:
    - Direct hydrogen use to sectors where it is most indispensable and cost-effective.
    - Support first-mover industries with tailored subsidy models.
- Advance Innovation and R&D:
    - Support pilot projects in offshore hydrogen production and hybrid systems (e.g., wind turbine-electrolyser).
    - Encourage modular and scalable technology designs.
- Foster Stakeholder Engagement:

- Build public trust through education and community-based innovation.
- Address workforce skills gaps and promote territorial integration.

• Societal Impacts:

- Enhanced energy security and autonomy through diversified hydrogen supply.
- Acceleration of the green transition and increased resilience of the EU energy system.
- Creation of sustainable jobs and support for regional development.

1. Introduction

The European Union's commitment to achieving climate neutrality by 2050 places hydrogen (H_2) at the heart of its energy transition strategies. As outlined in the European Green Deal, REPowerEU, and the EU Strategies on Energy System Integration and Offshore Renewable Energy, hydrogen is expected to decarbonize hard-to-electrify sectors, enhance system flexibility, and integrate growing shares of renewable electricity. However, the path from ambition to implementation has proven to be significantly more challenging than anticipated.

The Challenge - Despite robust political backing and a surge in project announcements, the deployment of hydrogen technologies across Europe faces major structural, financial, regulatory, and technological hurdles. Recent assessments—including the EC's 2025 SWD report and the analysis by Odenweller & Ueckerdt (2025)—reveal that the vast majority of hydrogen projects remain delayed, underfunded, or lack market viability. Gaps between planning and real-world progress threaten to undermine the EU's 2030 targets for renewable hydrogen production and usage, raising concerns about the realism and resilience of current implementation plans, including those formulated by the Implementation Working Group (IWG) Hydrogen.

Objectives of the Analysis - This SET4H2 D3.5 report addresses the critical need to:

- Align hydrogen deployment strategies with EU-wide decarbonization goals and cross-sector integration frameworks.
- Evaluate the coherence, gaps, and practical viability of the IWG Hydrogen IP - Implementation Plan (analysis of the IP adddressed both the draft version of 7th July 2025, and the final version of 22nd Oct 2025).
- Benchmark the IWG plan against deployment insights from the EU's flagship hydrogen programs (IPCEIs, ECH2A) and independent assessments like Odenweller & Ueckerdt (2025).
- Identify enablers, barriers, and missing components in current policy, technology planning, and investment frameworks.
- Provide actionable recommendations to ensure timely and effective deployment of hydrogen infrastructure, with particular emphasis on offshore renewable synergies.

From a methodologic perspective, this report uses a layered, interdisciplinary analytical approach, including:

- Policy and strategic review of EU legislation, hydrogen roadmaps, and regulatory frameworks.
- Comparative gap analysis between strategic ambitions (IWG, SET Plan, REPowerEU) and project-level realities drawn from EC reports and IEA data.
- Case studies and empirical data from hydrogen projects under IPCEI, ECH2A, and EU Member State programs.
- Critical assessment of the IWG Hydrogen Implementation Plan through the lens of deployment bottlenecks and implementation gaps, as the current energy transition brings holistic challenges and systemic transformations. The SET Plan framework has a key role therein to create a highly interconnected, efficient, and sustainable energy system across Europe. To achieve this, each technology analysis must be holistic to include non-technological dimensions as well.
- Cross-referencing with the findings of Odenweller & Ueckerdt , a world-wide analysis to identify potential levers for this particular SET Plan IWG to improve feasibility, risk, and market readiness of European hydrogen-related projects.
- This method ensures that the analysis is not only theoretically sound but also rooted in the operational challenges and systemic risks currently facing hydrogen deployment across Europe.

2. Policy Context

2.1 The EU Strategy for Energy System Integration

The EU Strategy for Energy System Integration (COM/2020/299 final), published on 8 July 2020, is a cornerstone of the European Green Deal. It outlines how the European Union plans to transform its energy system to achieve climate neutrality by 2050 through a more integrated, efficient, and sustainable approach.

The EU's current energy system is fragmented into sectoral silos—electricity, transport, heating, and industry operate largely independently. This leads to inefficiencies, such as waste heat and underutilized renewable energy. The strategy aims to break down these silos and create a flexible, interconnected energy system that supports deep decarbonization.

Energy system integration involves coordinated planning and operation across multiple energy carriers (electricity, gas, heat), infrastructures, and consumption sectors. The goal is to:

- Increase energy efficiency
- Maximize the use of renewables
- Reduce greenhouse gas emissions
- Lower system costs for consumers and businesses

The EU Strategy for Energy System Integration has three main pillars:

a. A More Circular Energy System

- Prioritizes energy efficiency ("energy efficiency first" principle)
- Promotes reuse of waste heat from industrial sites, data centres, and wastewater treatment
- Encourages local energy sources and community-level energy solutions
- Supports the Renovation Wave to improve building energy performance

b. Electrification of End-Use Sectors

- Pushes for direct electrification where feasible (e.g., heat pumps, electric vehicles)
- Expands renewable electricity generation (solar, wind)
- Plans for 1 million EV charging points across the EU
- Supports electric furnaces in industry and heat pumps in buildings

c. Promotion of Renewable and Low-Carbon Fuels

- Focuses on clean hydrogen, sustainable biofuels, and biogas
- Targets sectors where electrification is difficult (e.g., aviation, heavy industry)
- Introduces a classification and certification system for renewable and low-carbon fuels.

The strategy key actions and measures, including:

- Legislative revisions (e.g., TEN-E Regulation, Renewable Energy Directive)
- Financial support for innovation and infrastructure
- Research and deployment of new technologies
- Digital tools for smart energy management
- Guidance to Member States on fiscal policies and fossil fuel subsidy phase-out
- Market governance reform and infrastructure planning
- Consumer empowerment through better information and choices

The strategic outcomes by implementing this strategy, the EU aims to:

- Achieve climate neutrality by 2050
- Create a resilient, secure, and efficient energy system
- Foster economic growth and job creation
- Ensure environmental sustainability and resource efficiency

2.2 The EU Strategy for Offshore Renewable Energy Sources

The EU Strategy on Offshore Renewable Energy Sources (COM/2020/ 741 final), published on 19 November 2020, is a key component of the European Green Deal. It outlines how the EU plans to scale up offshore renewable energy to help achieve climate neutrality by 2050.
Offshore renewable energy, and offshore wind in particular, has become a mature, cost-effective technology. The EU sees it as an key element of the policy for:

- Meeting the 2030 climate target (at least 55% emissions reduction)
- Achieving net-zero emissions by 2050
- Supporting economic recovery and green jobs
- Europe already leads globally in offshore wind, and the strategy aims to consolidate and expand this leadership.

This strategy has ambitious targets and sets out clear capacity goals:

- 60 GW of offshore wind by 2030 (up from ~12 GW in 2020)
- 300 GW by 2050
- 40 GW of other ocean energies (wave, tidal, floating solar, algae-based biofuels) by 2050
- This represents a 25-fold increase in offshore wind capacity and a massive scale-up of emerging technologies.

Key Technologies are including offshore wind, ocean energy, floating solar and algae biofuels:

- Offshore Wind
  a. Most mature and cost-competitive
  b. Includes fixed-bottom and floating wind platforms
  c. Floating wind is crucial for deeper waters (e.g., Atlantic, Mediterranean)
- Ocean Energy
  a. Includes wave, tidal, ocean thermal, and salinity gradient technologies
  b. Still in early stages but with strong potential
- Floating Solar and Algae Biofuels
  a. Innovative solutions for space-constrained or remote areas
  b. Algae can be used for sustainable biofuel production

The strategic objectives include the integrated maritime planning, the grid infrastructure and interconnection, and the investment and financing:

- Integrated Maritime Planning
  a. Offshore energy must coexist with fishing, shipping, biodiversity, and defence
  b. Maritime Spatial Planning (MSP) is key to avoiding conflicts and optimizing space
- Grid Infrastructure and Interconnection
  a. Calls for a meshed offshore grid in the North Sea and beyond
  b. Promotes hybrid projects that combine generation and interconnection
  c. Supports cross-border cooperation and regional planning
- Investment and Financing
  a. Estimated investment needs: €800 billion by 2050
  b. EU funding tools: InvestEU, CEF, Horizon Europe, Innovation Fund, and Recovery and Resilience Facility
  c. Encourages public-private partnerships and blended finance

The market and regulatory framework is proposing market rules that support offshore hybrid projects, aims to harmonize permitting procedures across Member States, and encourages long-term power purchase agreements (PPAs) and contracts for difference (CfDs) to de-risk investments.

Innovation and industrial leadership support R&D in floating wind, ocean energy, and digitalization, promotes standardization and modular design to reduce costs, encourages skills development and reskilling for offshore jobs.
Environmental Sustainability addresses the offshore energy need to align with the EU Biodiversity Strategy, the emphasizes on environmental impact assessments, monitoring, and adaptive management, and the promotion of multi-use platforms and co-location (e.g., combining wind farms with aquaculture).
International cooperation, where the EU ambition is to become a global leader in offshore renewables. It supports technology exports, standards, and cooperation with neighbouring countries, and encourages regional sea basin strategies (North Sea, Baltic, Atlantic, Mediterranean, Black Sea).

To conclude, the EU Strategy on Offshore Renewable Energy aims to:

- Decarbonize the energy system
- Strengthen EU industrial leadership
- Create sustainable jobs
- Protect marine ecosystems
- Foster cross-border cooperation

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3. Technological Landscape

3.1 Role of H2 in the EU Strategy on Energy System Integration

Hydrogen is a key component in the EU's Strategy on Energy System Integration, where it is identified as a crucial element, either as a standalone energy carrier or as a hydrogen derivative, to decarbonize sectors where direct electrification is not feasible or cost-effective. This includes heavy industry, certain transport sectors (e.g., aviation, maritime, heavy-duty road transport), and as a feedstock in chemical processes.

This EU strategy emphasizes the production of hydrogen through electrolysis using renewable electricity, which is currently considered the cleanest and more effective method. However, in order to integrate hydrogen into a broader strategy, and not to miss the complexity of multi-vector energy systems and derivative markets, it is key to address Power-to-X (P2X) pathways as well, in order to include hydrogen derivatives (e.g. ammonia, methanol, e-fuels). In fact, besides enabling the integration of large shares of variable renewable energy, by providing long-term storage and buffering capabilities, the renewable hydrogen in the P2X equation enables the production of those hydrogen derivatives. In brief, hydrogen can be used in industrial processes, heavy-duty transport, and as a feedstock for producing synthetic fuels and green fertilizers. For a more detailed approach on P2X strategies, the SET4H2 project deliverable D3.4 on mapping H2 value chains provides key insights on both a technology and process basis, and in a quite comprehensive way as it emphasizes that hydrogen derivatives are pivotal for decarbonizing hard-to-electrify sectors and enabling sector coupling. It also details their role in industrial demand and transport (aviation, shipping) and the need for modular, fit-for-purpose architectures

Hydrogen plays a nodal role in an integrated energy system, linking electricity and gas markets. Electrolysers can convert renewable electricity into hydrogen, which can then be used in various applications, providing flexibility and storage solutions.

The strategy highlights the need for dedicated infrastructure for hydrogen production, storage, and transportation. This includes the potential repurposing of existing natural gas infrastructure and the development of new hydrogen pipelines and refuelling stations.

The EU is introducing a comprehensive terminology and certification system for renewable and low-carbon hydrogen to distinguish it from more polluting energy sources. This system aims at being based on full life cycle greenhouse gas emissions savings. The strategy also considers establishing minimum shares or quotas for renewable hydrogen in specific end-use sectors to promote its uptake.

Financial support for hydrogen projects is crucial, including through EU funding mechanisms like Horizon Europe, InvestEU, and the Innovation Fund. The strategy also mentions the potential for market-based mechanisms, such as carbon pricing and contracts for difference, to support hydrogen deployment.

While that EU strategy outlines the importance of hydrogen, it does not provide specific, detailed roadmaps and targets for hydrogen production, infrastructure development, and market integration. Clear milestones and timelines would help guide MSs and industry stakeholders. The EU strategy mentions the need for infrastructure but does not provide a detailed plan for the development and integration of hydrogen infrastructure across the EU. This includes the coordination between hydrogen production sites, storage facilities, and end-use applications. More detailed sector-specific strategies for hydrogen use in industries like steel, chemicals, and heavy transport would be beneficial. This includes identifying the specific technological and economic challenges in each sector and proposing tailored solutions. The strategy could benefit from a stronger focus on consumer and public engagement to build acceptance and support for hydrogen technologies. This includes educational campaigns and stakeholder consultations to address safety concerns and promote the benefits of hydrogen.

The EU strategy should better integrate hydrogen with other EU policies, such as those on renewable energy, industrial strategy, and transport. This would ensure a cohesive approach and maximize synergies between different policy areas. While the strategy mentions the importance of innovation, it could provide more details on specific research and development priorities for hydrogen technologies. This includes funding for pilot projects, demonstration plants, and collaboration with research institutions.

Scaling up hydrogen deployment in the EU to support the EU Strategy on Energy System Integration involves a complex interplay of enablers and challenges (Table 1 and Table 2).

Table 1: Key enablers in scaling up H2 deployment in the energy system integration.

Enabler	Description
Robust Policy and Regulatory Frameworks	The Hydrogen and Gas Decarbonisation Package (effective August 2024) introduce the first dedicated EU-wide regulatory framework for hydrogen infrastructure. RED III (Renewable Energy Directive) sets binding targets for renewable hydrogen use in industry and transport.
Infrastructure Development	Initiatives like the European Hydrogen Backbone (EHB) aim to repurpose existing gas pipelines for hydrogen transport. Investment in hydrogen-ready LNG terminals and underground hydrogen storage enhances system flexibility.
Financial Support Mechanisms	EU funding instruments such as the Connecting Europe Facility (CEF) and Important Projects of Common European Interest (IPCEI) help de-risk investments. Proposals for hydrogen-specific Contracts for Difference (CfDs) aim to bridge the cost gap between grey and green hydrogen.
Cross-sector Integration	Hydrogen enables sector coupling by adopting P2X strategies, linking electricity, heating, transport, and industry. Electrolysers provide grid flexibility by absorbing excess renewable electricity
International Partnerships	The EU is fostering hydrogen trade with regions like North Africa and the North Sea, ensuring diversified and resilient supply chains.

Table 2: Key challenges in scaling up H2 deployment in the energy system integration.

Challenge	Description
High Production Costs	Green hydrogen remains significantly more expensive than fossil-based alternatives, limiting competitiveness without subsidies.
Infrastructure Gaps	Lack of a fully developed hydrogen transport and storage network hinders large-scale deployment. Permitting delays and regulatory fragmentation across member states slow progress.
Market Uncertainty	Investors face unclear demand signals and volatile policy environments, leading to project cancellations or delays.
Technology Readiness and Scalability	Many hydrogen technologies (e.g., high-capacity electrolysers, hydrogen turbines) are still in early deployment stages. Standardization and certification of hydrogen quality and origin are still evolving.
Public Acceptance and Skills Gap	Concerns over safety, land use, and environmental impact can delay projects. A shortage of skilled labour in hydrogen-related fields could bottleneck growth.

Due to the complex integration efforts in the energy system, there is a key role for the SET Plan to promote and assist the creation of a highly interconnected, efficient, and sustainable energy system across Europe. To achieve such mission, technology analysis therein cannot focus solely on the technical aspects—it must also include non-technological dimensions. There are multiple causes for it, that we might clusterise as follows:

1. Complexity of Energy Systems
Energy systems are not just technical infrastructures; they are socio-technical systems involving:

- Multiple sectors (electricity, heating, transport, industry)
- Stakeholders (governments, businesses, consumers)
- Regulatory frameworks and market structures

Integration requires aligning these diverse elements, which goes beyond technology alone.

2. Non-Technological Dimensions Drive Adoption
Even the most advanced technology will fail if:

- Regulatory barriers prevent deployment (e.g., grid codes, permitting)
- Economic incentives are misaligned (e.g., lack of carbon pricing)
- Social acceptance is low (e.g., resistance to wind farms or hydrogen pipelines)

Thus, policy, market design, and societal engagement are as critical as technical performance.

3. EU SET Plan Objectives
The SET Plan emphasizes:

- Cost reduction and competitiveness
- Market uptake and scalability
- Environmental and social sustainability

Thus these goals require considering:

- Business models
- Skills and workforce development
- Environmental impact assessments

4. Systemic Interdependencies
Technologies interact with:

- Infrastructure (e.g., smart grids, storage)
- Digitalization (data platforms, cybersecurity)
- Behavioral patterns (consumer flexibility, prosumer models)

Ignoring these dimensions risks creating bottlenecks or stranded assets.

In short, technology analysis must integrate policy, economics, social factors, and environmental considerations because energy transition is not just a technical challenge—it's a systemic transformation along the energy transition.

All that said, there are strong reasons to believe that hydrogen is a central element in the EU's strategy for energy system integration. It offers solutions for decarbonizing hard-to-electrify sectors, providing as well flexibility and storage for renewable energy. However, this strategy could be strengthened and the new SET Plan IWG H2 has a key role there - depending on predefined contexts and system boundaries, as proposed in the SET4H2 project WP3 deliverables: D3.4 referred above, and on the D3.2 "Analysis Report on H2 in IPs of other IWGs".

3.2 Role of H2 in the EU Strategy on Offshore Renewable Energy

When integrating offshore renewable energy into the broader energy system, Hydrogen is highlighted as a system element, and offshore wind energy is seen as a significant source for producing renewable hydrogen through electrolysis.

The offshore renewable energy systems (ORES) strategy emphasizes the potential for offshore wind farms to produce hydrogen directly at sea. This involves using electrolysers to convert the electricity generated by offshore wind turbines into hydrogen, which can then be stored and transported via pipelines or ships. Offshore wind farms provide high and stable load factors, reducing variability risks compared to onshore renewables. This improves electrolyser utilization and lowers the levelized cost of hydrogen (LCOH).

Combining offshore wind with hydrogen production can reduce overall LCOE compared to standalone systems, leveraging shared infrastructure and economies of scale. Offshore hydrogen production is considered a viable option to deliver energy onshore, especially in cases where direct electricity transmission is challenging or costly.

The development of hydrogen infrastructure, including pipelines and storage facilities, is seen as crucial for the large-scale deployment of offshore renewable energy. This infrastructure would enable the efficient transport and storage of hydrogen produced offshore. Offshore hydrogen production enables off-grid operation, avoiding costly subsea power cables and reducing transmission losses. The strategy suggests that offshore hydrogen production and pipelines should be considered in the planning and development of both electricity and gas grids. In addition, Hydrogen can be shipped directly from offshore platforms to demand centers, bypassing electricity grid constraints and enabling international trade. These projects can optimize the use of maritime space and reduce costs by integrating multiple functions, such as electricity generation, hydrogen production, and cross-border interconnections. This ORES strategy calls for a clear regulatory framework to support the development of offshore hydrogen projects. This includes addressing market rules, grid connection requirements, and the allocation of costs and benefits among stakeholders. The EU plans to introduce a comprehensive terminology and certification system for renewable hydrogen to ensure its traceability and sustainability.

The concept of hybrid projects, which combine offshore renewable energy generation with hydrogen production, is promoted and key challenges acknowlwdged such as:

a) Offshore electrolysis systems still have to manage high Capex and Opex, due to expensive platforms, subsea pipelines, and specialized maintenance, which increase project costs.
b) Offshore electrolysis and hydrogen transport technologies are still at early demonstration stages.
c) Offshore hydrogen projects face lengthy permitting processes and lack harmonized EU standards, delaying implementation.
d) Potential impacts on marine ecosystems and conflicts with other maritime activities (fisheries, biodiversity) require careful assessment and stakeholder engagement.
e) Hydrogen pipelines and storage facilities are underdeveloped, and integration with the European Hydrogen Backbone remains conceptual.

Research and innovation are thus identified as critical for advancing hydrogen technologies. This includes developing new designs for offshore electrolysers, improving the efficiency of hydrogen production, and integrating hydrogen with other renewable energy sources. The strategy highlights the need for pilot and demonstration projects to test and scale up offshore hydrogen production technologies.

While the ORES strategy enables a framework to produce hydrogen in offshore conditions, it misses detail on specific roadmaps and targets to explore such potential. Clear milestones and timelines for the development and deployment of offshore hydrogen projects would provide better guidance for stakeholders. Though the strategy mentions the need for hydrogen infrastructure, there was no room enough to provide a detailed plan for its development. This includes the coordination between offshore hydrogen production sites, storage facilities, and transportation networks. More detailed sector-specific strategies for hydrogen use in industries like steel, chemicals, and heavy transport would be beneficial. This includes identifying the specific technological and economic challenges in each sector and proposing tailored solutions. The ORES strategy could benefit from a stronger focus on consumer and public engagement to build acceptance and support for hydrogen technologies. This includes educational campaigns and stakeholder consultations to address safety concerns and promote the benefits of hydrogen. This strategy should better integrate hydrogen with other EU policies, such as those on renewable energy, industrial strategy, and transport. This would ensure a cohesive approach and maximize synergies between different policy areas. While the strategy mentions the importance of innovation, it could provide more details on specific research and development priorities for hydrogen technologies. This includes funding for pilot projects, demonstration plants, and collaboration with research institutions. In line with that perspective, the SET4H2 project deliverable D3.2 "Analysis Report on H2 in IPs of other IWGs" is making a proposal on the creation of a SET Plan IWG H2 activity focusing on: "Hybrid Offshore Deployment: Collaborate with Wind and Ocean IWGs to develop offshore hydrogen production hubs using hybrid renewable systems", which draws from back experience of one of the authors of this D3.5 on the endorsement and kick-off of the IEA Task 46 OH2P in the frame of the ExCo of IEA Hydrogen TCP.

Table 3: Scaling up H2 deployment in offshore renewable energy systems - Key enablers.

Enabler	Description
)ffshore Wind-Hydrogen Synergies	Offshore wind farms can directly power electrolysers located offshore or near the coast, producing green hydrogen at source. This reduces grid congestion and enables energy storage and transport via pipelines or ships.
Hydrogen Infrastructure Development	The European Hydrogen Backbone (EHB) aims to connect offshore production sites with inland demand centers. Repurposing LNG terminals and building hydrogen-ready ports supports large-scale hydrogen logistics.
EU Policy and Funding Support	The REPowerEU plan targets 10 million tonnes of domestic renewable hydrogen production by 2030. Funding from CEF, IPCEI, and Innovation Fund supports offshore hydrogen pilot projects.
System Integration and Flexibility	Hydrogen provides seasonal storage and balancing services for variable offshore renewables. Electrolysers can act as grid-stabilizing assets, absorbing excess offshore wind power.
Technological Innovation	Advances in offshore electrolysis, subsea hydrogen pipelines, and liquid hydrogen carriers are enabling new deployment models.

Table 4: Scaling up H2 deployment in offshore renewable energy systems - Key challenges.

Challenge	Description
High Costs and Investment Risks	Offshore hydrogen production is capital-intensive, with high costs for electrolysers, platforms, and transport infrastructure. Lack of bankable offtake agreements increases investor uncertainty.
Infrastructure and Permitting Bottlenecks	Delays in permitting offshore hydrogen infrastructure and lack of harmonized standards across EU countries slow deployment. Grid connection and seabed use conflicts with other marine activities (e.g., fisheries, conservation) add complexity.
Market and Regulatory Uncertainty	Unclear hydrogen market design, pricing mechanisms, and certification schemes hinder long-term planning. Variability in national implementation of EU directives (e.g., RED III) creates fragmentation.
Technology Readiness	Offshore electrolysis and hydrogen transport technologies are still in early demonstration phases, with limited commercial-scale deployments.
Environmental and Social Concerns	Potential impacts on marine ecosystems, visual landscapes, and coastal communities require careful assessment and stakeholder engagement.

Scaling up hydrogen deployment to support the EU Offshore Renewable Energy Strategy involves leveraging hydrogen as a flexible energy carrier that can store and transport offshore wind power, and a complex interplay of enablers and challenges (Table 3 and Table 4).

To conclude:

a) Offshore hydrogen supports EU targets for offshore renewable integration and energy system flexibility, aligning with REPowerEU and SET Plan objectives.
b) Hydrogen plays a role in the EU's ORES strategy by offering solutions for integrating renewable energy into the broader energy system and providing flexibility and storage.
c) The SET Plan IWG H2 Implementation Plan is not addressing it yet. The integration of a comprehensive framework and dedicated activity on “Hybrid Offshore Deployment”, as proposed by the SET4H2 project deliverable D3.2 “Analysis Report on H2 in IPs of other IWGs”, is likely to fullfil that gap. Having such a hypothetical contribution from the SET Plan IWG Hydrogen, this EU strategy could be strengthened by providing more detailed planning tools, infrastructure planning, sector-specific strategies, and stronger integration with other policies. Enhanced focus on stakeholders’ engagement and innovation would also support therein a successful deployment of hydrogen technologies.

3.3 The Implementation Plan of the IWG Hydrogen (SET Plan)

This section aims to address the strategy and the methodology being adopted in the SET Plan IWG Hydrogen Implementation Plan final version by 22 october 2025. Its expected role consists on being key to facilitate an alignment of EU-level H2-oriented research and innovation (R&I) with the European Green Deal, REPowerEU, the Net-Zero Industry Act, and the SET Plan IWGs when hydrogen is already being applied or has potential to be applicable.
However, having in perspective that potential in the SET Plan framework, when contrasted with systemic, H2 value chain-oriented and holistic published approaches reported in the SET4H2 WP3 deliverables, important additional strategic and methodological development areas emerge together with the need in the SET Plan to move beyond a more conventional technology-centric approach in order to become systemic and holistic – when in particular a new H2-oriented IWG is being launched - to integrate key dimensions such as:

- System-level P2X strategies and hydrogen derivatives
- Value chain and raw material considerations
- Infrastructure and industrial scale-up aligned with NZIA
- Cross-IWG governance for synergies
- Policy harmonization and market creation
- Skills development and societal engagement

Being more deeply explored in the next section on challenges and drawbacks reported so far at a worldwide scale on H2 implementation, those challendges and drawbacks enable to classify H2 implementation gaps into technological and non-technological categories:

Technological Gaps
These relate to technology maturity, performance, and integration challenges:

1. Low Technology Readiness Levels (TRL)
    - Electrolyser and fuel cell technologies are less mature than expected.
    - Many projects involve first-of-a-kind designs, making commissioning and scaling complex.
2. Reliability and Lifespan Issues
    - Electrolysers exhibit low reliability and shorter lifespans than anticipated.

3. System Integration Complexity
    - High integration costs, especially for maritime and offshore applications.
    - Component incompatibilities during commissioning.
4. Infrastructure Readiness
    - Delays in hydrogen transport and storage infrastructure (pipelines, storage hubs).
    - Integration of new pipelines into existing energy systems remains technically complex.
5. Electricity and Resource Constraints
    - Grid access delays and congestion.
    - Challenges in sourcing water for electrolysis in certain regions.

In the synthesis provided on Table 5, the aim is to offer an analysis and recommendations focusing on a selection of those technological and non-technological shortcomings, and subsequent for updating the IWG H2 IP.

Table 5: Recommendations to address technological and non-technological shortcomings.

Dimension of analysis	Recommendation	Action
Adopt a Systemic P2X Framework	**Integrate Power-to-X (P2X) strategies** into the plan, covering hydrogen derivatives (ammonia, methanol, e-fuels) as core pillars.	As derivatives are essential for flexibility and sector coupling, include a dedicated section on P2X technologies and their role in decarbonizing hard-to-electrify sectors (aviation, shipping, heavy industry).
Map and Secure Value Chains	**Add a comprehensive value chain analysis** for hydrogen and derivatives, from feedstock (energy, water, CO_2, nitrogen) to end-use sectors, and raw material considerations.	As raw material dependency and recycling are key enablers for sustainability and resilience, incorporate critical raw materials (e.g., platinum, iridium, nickel) and circularity strategies (recycling, reuse) into the roadmap.
Plan for Industrial and Infrastructure Scale-Up	**Include infrastructure targets** for pipelines, refuelling stations, storage hubs, and integration with renewable generation and CCUS.	As industrialization and infrastructure gaps are major barriers, align with NZIA targets (40% EU manufacturing capacity for electrolysers and fuel cells by 2030) and set permitting acceleration goals.
Establish Cross-IWG Governance	**Create a Cross-IWG Task Force** under the Hydrogen IWG to operationalize synergies with other IWGs (Wind, Ocean, PV, CCUS, Energy Systems).	As there are fragmented efforts and a recommended structured coordination to unlock systemic benefits, define joint R&I activities (e.g., offshore hydrogen hubs, hybrid renewable systems, systemic Power-to-X projects)
Strengthen Policy and Market Framework	**Embed regulatory harmonization and certification schemes** (REDIII, RFNBO compliance) into the plan.	As policy clarity and market incentives are key enablers, include mechanisms for market creation (e.g. Hydrogen Bank auctions, public procurement policies) and address the supply-demand "chicken-and-egg" problem.
Develop Skills and Social Engagement Strategy	**Add a workforce development program** with training standards, modular courses, and hydrogen education hubs.	As lack of skilled workforce and social acceptance are major barriers to deployment, launch stakeholder engagement campaigns to build public trust and awareness of hydrogen's benefits.

Non-Technological Gaps

These involve policy, regulatory, financial, and market-related barriers:

1. Permitting Bottlenecks
    - Lengthy, unpredictable, and inconsistent permitting processes.

- Lack of hydrogen-specific regulatory frameworks.

2. Public Funding Issues
   - Delayed approvals and insufficient aid to make projects bankable.
   - Inflation and raw material price hikes worsening funding gaps.
3. Off-Taker Uncertainty
   - Industries reluctant to pay green hydrogen premiums.
   - Lack of long-term offtake agreements undermines project viability.
4. Market and Investment Challenges
   - Nascent hydrogen market with unclear demand signals.
   - Cost volatility and lack of carbon pricing mechanisms.
5. Fragmentation and Regulatory Inconsistency
   - Uncoordinated national regulations and standards.
   - Conflicting definitions of renewable hydrogen and redundant certification schemes.
6. Skills Gap and Public Acceptance
   - Shortage of skilled workforce for hydrogen technologies.
   - Safety and environmental concerns delaying projects.

4. Challenges and drawbacks on H2 implementation

3.4 Lessons from hydrogen deployment in EU

3.4.1 Implementation and monitoring of large-scale projects

The analysis provided in a recent report on large-scale hydrogen deployment projects EC (2025)[1], based on the implementation and monitoring of large-scale hydrogen deployment projects, includes the state of execution of four IPCEI Hy2Waves: Hy2Tech, Hy2Use, Hy2Infra, and Hy2Move - on which the Commission approved State aids (2022-2024) - and also the project portfolio of the European Clean Hydrogen Alliance (ECH2A). The in-depth assessment that is provided confirms the challenging situation of the sector. Overall, in the frame of IPCEI-H2 projects, despite ambitious plans and political momentum, hydrogen project implementation has faced substantial delays, uncertainties, and setbacks. By the end of 2024, 17 projects had reached final investment decision status and were under construction. Out of 122 IPCEI-approved projects, 10 have withdrawn, and nearly two-thirds of active projects are off track, due to different challenges in implementation:

- Delays in final investment decisions (FIDs).
- Late or uncertain public funding.
- Difficulty securing off-take agreements (customers for hydrogen).
- Rising capital and operational costs.

Substantial delays have also been reported due to lower TRL than expected:

- Electrolyser and fuel cell technologies are less mature than expected.
- Many projects involve first-of-a-kind technologies, making design, commissioning, and scaling more complex.
- Challenges include:
    i. Low reliability and lifespan of electrolysers.
    ii. High system integration costs (especially in maritime applications).
    iii. Delays during commissioning due to component incompatibilities.

Financial and regulatory hurdles have also been reported, including public funding issues, off-taker uncertainty, and permitting-related delays:

- Public Funding Issues
    i. Delayed funding approvals in Member States (e.g. Spain and Germany).
    ii. Even approved aid is often insufficient to make projects bankable due to cost escalations and market risks.
    iii. Some participants proceed at their own risk without confirmed support.
    iv. Increased inflation and raw material prices worsened the funding gap.
- Off-Taker Uncertainty
    i. Industries are reluctant to pay the premium for green hydrogen.
    ii. Lack of commitment from industrial clients delays project bankability.
- Permitting-related delays
    i. Unpredictable, lengthy, and bureaucratically inconsistent.

[1] EC (2025), Report on large-scale hydrogen deployment projects, covering the EU's efforts to scale up clean hydrogen through IPCEIs and the European Clean Hydrogen Alliance (ECH2A), SWD (2025) 121 final (12 may).

ii. Lacking standardised hydrogen-specific frameworks.
iii. Based on outdated regulations unsuited to hydrogen technology.

Energy access and infrastructure constraints have been reported on electricity supply Issues, and storage and transport bottlenecks:

- Electricity Supply Issues
  - i. Projects rely on PPAs with renewable energy suppliers, but:
  - ii. Grid access is often delayed.
  - iii. Tariffs and PPA costs are higher than anticipated.
  - iv. Grid congestion is a recurring issue.
  - v. Challenges also include sourcing water for electrolysis in certain regions.
- Storage and Transport Bottlenecks
  - i. Lack of hydrogen infrastructure limits deployment.
  - ii. Projects under Hy2Infra aim to address this, but infrastructure won't be in place until 2026–2029.
  - iii. Integration of new pipelines into existing energy systems remains technically and politically complex.

Market and investment challenges have been reported on nascent market, and cost volatility:

- Nascent Market:
  - i. Hydrogen demand is still underdeveloped.
  - ii. Customers (especially in hard-to-abate sectors) are hesitant to commit without guaranteed volumes and prices.
  - iii. This delays FIDs and creates a vicious cycle of underutilisation and low investor confidence.
- Cost volatility:
  - i. Rapid inflation, material shortages, and uncertainty in green electricity pricing have inflated CAPEX and OPEX.
  - ii. Giga factories for electrolysers are underutilised due to lack of downstream demand.

On specific IPCEI H2 project implementation, the following key findings should be underlined:

- IPCEIs status on Hy2Tech & Hy2Use - Of 66 projects in Hy2Tech and Hy2Use:
  - i. 24.2% have not yet started.
  - ii. 39.4% are delayed or seeking extension.
  - iii. Only 18.2% are on schedule.
  - iv. Just 5 projects had reached FID as of late 2024.
- IPCEIs status on Hy2Infra: Although most projects have started implementation and received funding, about 60% are already behind schedule. Delays mirror those seen in earlier IPCEIs.
- IPCEIs status on Hy2Move: Too early for implementation data (kick-off held in October 2024).

The challenges identified within the ECH2A projects pipeline are the following:

- From the original 840 projects, only 425 remain in the updated pipeline.
- Only 77 projects had reached FID by December 2024.
- Many milestones remain unmet, including permitting, land acquisition, and PPAs.
- Significant data gaps exist due to lack of mandatory reporting requirements.
- Public funding remains essential; almost no projects reached FID without public aid.

Structural and strategic drawbacks were identified with a focus on overambition in early planning and on fragmentation:

- Overambition in Early Planning: Projects conceived 3–4 years ago under optimistic scenarios are proving premature. As a result, many require redesigns, extensions, or face abandonment.
- Fragmentation: Member States often pursue uncoordinated regulations and standards, leading to:

i. Barriers to cross-border hydrogen trade.
ii. Conflicting definitions of renewable hydrogen.
iii. Redundant certification schemes.

Market coordination was addressed, and evidence shows there was absence of unified market signals or carbon pricing mechanisms to make renewable hydrogen price-competitive with fossil alternatives.

To conclude, and despite major support and strategic alignment at EU level, large-scale hydrogen deployment in the EU is facing a challenging landscape. This EC report identifies several challenges that need to be addressed at both national and EU levels, including funding support, regulatory issues, and market readiness. Key takeaways include:
• Delays and underperformance dominate the IPCEI landscape, though recent FIDs in Hy2Infra provide some momentum.
• Funding gaps, regulatory ambiguity, immature technologies, and a lack of demand-side support are persistent hurdles.
• Hydrogen market creation needs coordination between EU, national governments, and industry, alongside stronger monitoring tools.
• The Clean Industrial Deal (2025) may help redesign IPCEI structures, and accelerate funding decisions, namely strengthening support for industrial decarbonization and clean tech manufacturing in the EU.

Ultimately, the EU's hydrogen ambitions remain technically viable but strategically fragile, requiring more agile governance, better risk-sharing instruments, and integrated market development efforts.

3.4.2 How is the IWG H2-IP addressing challenges and drawbacks related with large-scale hydrogen deployment

The IWG H2 IP has taken key steps to address strategic R&I priorities at different times frames. However, as reported namely in the EC.SWD(2025) 121 final, several critical implementation gaps remain in Europe that limit the ability to tackle the urgent challenges on adoption and diffusion of this technology. An assessment of what is missing or insufficiently addressed in the technology value chain, which necessarily includes the SET Plan and next the rollout stage of the technology in the NZIA, is shown below.

What the IWG H2 IP is covering well

- Long-term R&I vision until 2050, including basic and low-TRL hydrogen production technologies.
- Broad scope across the hydrogen value chain: production, transport, storage, end-use, and cross-cutting issues.
- Strong commitment to coordination within the SET Plan and synergies with EU partnerships (CHJU, CETP).
- Emphasis on hydrogen valleys, system integration, and sector coupling.
- Attention to PFAS replacement, circularity, and raw material dependency.
- -Recognition of the need for socio-economic, environmental, and legal enablers.

Recommendations to address problems reported by EC.SWD(2025)

1. Implementation Readiness and Deployment Bottlenecks

Over two-thirds of IPCEI projects are found to have a delay or be off track due to permitting, off-take uncertainty, and financing bottlenecks. Concrete actions or policy proposals should be pursued to accelerate permitting processes, to reduce off-taker risk through support for demand creation (e.g., Contracts for Difference, offtake guarantees), as well as to streamline project bankability, precommercial risk-sharing, or de-risking strategies. The IWG should determine where it can make a substantial contribution to overcome these bottlenecks.

2. Project Monitoring and Data Transparency
There is a lack of harmonised data reporting across IPCEIs and the ECH2A project pipeline that hinders oversight and coordination. The IWG H2 could focus on developing a framework for mandatory or harmonised monitoring of the progress of hydrogen projects. This includes the integration with existing EU monitoring tools (e.g. ECHO, EIGL, JRC KPIs) and the improvement of data availability and comparability across Member States and project types.

3. Short-Term Actions for Near-Term Targets (2025–2030)
EU's 2030 targets (10 Mt domestic production) are at risk due to deployment lags. Most strategic targets in the IP do not mention a specific timeframe; the first activity fiches cover a period from 2025 to 2035/40. It is recommended to put a stronger focus on near-term implementation or accelerated demonstration programs (e.g. 2025–2028). A more general challenge remains in developing a clear roadmap or interim KPIs to guide industry on the pathway from TRL 7–9 to market-ready systems by 2030.

4. Demand-Side Support and Market Creation
Off-take agreements are a major barrier due to cost uncertainty and limited consumer willingness to pay. The IWG should investigate how it can support market activation tools (e.g. quotas, CfDs, product standards) and first-mover industries (steel, ammonia, methanol) in closing the green premium gap. In addition, a coordination mechanisms between supply and demand development could be a promising approach to support market creation by avoiding stranded electrolyser assets.

5. Permitting and Regulatory Streamlining
Permitting remains a critical source of delay, cited across nearly all project types. So far, no specific actions on "legal" aspects are proposed by the IWG to systematically identify hydrogen-specific permitting rules, to diminish national permitting inconsistencies, and to reduce unpredictability in administrative approvals.

6. Funding Alignment and Investment Coordination
IPCEI projects suffer from delayed national aid, inflation-driven cost overruns, and lack of aligned funding windows. A valuable contribution of the IWG would be to support the synchronisation of public funding (EU and national), to support or use funding alignment mechanisms like the European Hydrogen Bank or auction-based support, and to integrate de-risking instruments for project developers and manufacturers (e.g. insurance, guarantees).

7. Project Pipeline Resilience and Fallback Strategies
Dozens of IPCEI and ECH2A projects have been abandoned or re-scoped. The IWG is recommended to discuss flexibility mechanisms, the reallocation of funding from failing projects, or strategies to mitigate project abandonment. A framework for project triage or acceleration based on maturity or strategic importance would be also required in this context.

8. Transport & Storage Infrastructure Acceleration
Infrastructure development (e.g. Hy2Infra) is significantly delayed, and readiness is poor. Binding milestones or prioritisation criteria for pan-European infrastructure including legal frameworks for cross-border pipelines, blending, or third-party access should be developed by the IWG, and coordination with the EHB (Hydrogen Backbone) should be sought.

To conclude, with reference to the findings of EC. SWD(2025) 121 final, while the SET Plan and the IWG's first IP provides a strong R&I framework for a mid-to-long-term hydrogen deployment within the implementation of the NZIA regulation, it does not yet offer the operational tools, governance mechanisms, or urgency needed to contribute to overcoming the real-world deployment challenges reported in that EC report. To bridge those gaps, recommendations for the next update of the IWG's Implementation Plan were produced.

3.5 Lessons from IEA on hydrogen deployment

A 2025 analysis by Odenweller & Ueckerdt "The green hydrogen ambition and implementation gap"[2], by tracking in the IEA Hydrogen Projects Database 190 green H2 projects over 3 years, identified a wide 2023 implementation gap[3] with only 7% of global capacity announcements finished on schedule. That analysis starkly documents a global "green hydrogen implementation gap", underscoring the systemic issues in translating ambition into real-world progress. This section focuses on specific aspects the next update of the IWG's IP should take into consideration to address the challenges highlighted by Odenweller & Ueckerdt, identifying critical shortcomings in strategic focus, methodology, and policy framing that may hamper real progress by 2030 and beyond.

Overview of Odenweller & Ueckerdt's Key Findings
Three critical gaps are identified:

- 2022–2023 Implementation Gap: Only 7% of announced projects were realized on time.
- 2030 Ambition Gap: Largely closed on paper due to massive project announcements.
- 2030 Implementation Gap: Most projects lack concrete policy or financial backing, and up to $1.3 trillion in subsidies may be required to close the cost gap to fossil fuels.

These gaps stem from:

- Unreliable project announcements.
- Lack of bankable business models.
- Excessive reliance on "kickstart" narratives instead of long-term policy frameworks.
- Absence of demand-side certainty (e.g., off-take agreements).
- Underestimation of scale-up challenges and infrastructure dependencies.

Derived recommendations for the IWG Hydrogen
1. Realistic Growth Pathways and Technology Diffusion Models
Odenweller & Ueckerdt emphasize the need for realistic growth models based on historical learning rates and technology diffusion challenges (e.g., non-modular plant designs, complex system integration). Quantitative roadmaps or feasibility space modelling (incl. monitoring indicators, KPIs) could help to describe realistic growth pathways for hydrogen production technologies of different stages of maturity that are within the scope of the IWG (electrolysis, thermochemical, photochemical).

2. End-Use Viability and Market Prioritization
The IWG references potential applications (e.g., steel, transport, chemicals), but does not prioritize sectors based on cost-efficiency or irreplaceability — a key policy recommendation from the paper. According to Odenweller & Ueckerdt's, green hydrogen should first be directed to hard-to-electrify sectors where it is most indispensable, due to high subsidy needs, long-term reliance on policy support without carbon pricing and uncertain demand. Sectoral prioritization criteria and comparative modeling such as hydrogen vs. alternatives (e.g., direct electrification, biofuels) could support the development of a specific strategic focus for hydrogen application.

3. Policy Support Instruments and Subsidy Pathways
Odenweller & Ueckerdt emphasize the need for a balanced policy mix, combining supply-side subsidies with demand-side regulation, as well as the importance of carbon pricing to reduce long-term subsidy needs. The quantification of subsidy needs over time, the modeling of carbon pricing

[2] Odenweller & Ueckerdt, Nature Energy 10: 110–123, January 2025. https://doi.org/10.1038/s41560-024-01684-7
[3] Implementation gap: Difference between announced and realized projects

scenarios, and the creation of a sustainable financial architecture for long-term support could be meaningful approaches for the IWG to address these needs.

4. Tracking and Accountability
Odenweller & Ueckerdt advocatetracking project-level data to expose gaps and recommend continuous evaluation as a best practice. The IWG’s implementation progress should be monitored by means of performance tracking mechanisms (e.g., realized vs. announced capacity) and transparency tools (e.g., dashboards, public databases) including independent reviews.

5. Technology Neutrality and Diversification
The IWG promotes technological neutrality (e.g., including emerging technologies like photochemical and thermochemical splitting), arguing it enhances Europe’s resilience. However, Odenweller & Ueckerdt caution that over-diversification could dilute focus and that resource allocation should reflect probabilistic feasibility. Prioritizing mature, scalable technologies (like PEM and AEL electrolysis) would ensure nearer-term returns.

5. Conclusions

Hydrogen is a pillar of EU Decarbonization. However, evidence shows that its strategic potential is facing structural challenges.

Hydrogen, either as a energy vector or industrial commodity, has been positioned as a cornerstone of the European Union's decarbonization strategy, underpinning ambitions for climate neutrality by 2050. Its strategic role spans multiple dimensions: decarbonizing hard-to-electrify sectors such as heavy industry, maritime transport, and aviation; enabling system flexibility through long-duration energy storage; and facilitating sector coupling via Power-to-X pathways. Furthermore, hydrogen is pivotal for integrating offshore renewable energy sources into the broader energy system, offering solutions for energy transport and storage where direct electrification is impractical.

However, the findings of this study reveal a persistent and significant gap between ambition and implementation. Despite robust policy frameworks and unprecedented project announcements, real-world progress remains constrained by structural, financial, regulatory, and technology-related barriers. These challenges threaten the EU's ability to meet its 2030 targets for renewable hydrogen production and utilization, raising concerns about the resilience and realism of current strategies that require to be tackled.

Key Insights

1. Strategic Potential vs. Operational Reality

Hydrogen's potential is undisputed, but deployment is lagging. Lessons from IPCEI projects and the European Clean Hydrogen Alliance pipeline show systemic delays, cost overruns, and project cancellations. By late 2024, only a fraction of announced projects had reached Final Investment Decision (FID), and many remain off track due to permitting bottlenecks, funding gaps, and lack of offtake agreements.

2. Technological and Non-Technological Gaps

Technological challenges include low Technology Readiness Levels (TRLs) for electrolysers and offshore hydrogen systems, reliability issues, and integration complexities. Non-technological barriers—such as fragmented regulations, permitting delays, and market uncertainty—are equally critical. These factors collectively undermine investor confidence and slow industrial-scale deployment.

3. Policy and Governance Shortcomings

The EC.SWD(2025) 121 final – which characterise the EU landscape on H2 related matters – collected implementation gaps as well as the related near-, mid-term deployment challenges. Missing elements include mechanisms for accelerating permitting, harmonizing regulations, creating demand-side incentives (e.g., Contracts for Difference), and establishing robust monitoring frameworks.

4. Offshore Renewable Integration

Offshore hydrogen production offers promising synergies with wind energy, and other renewable energy mixes, in order to reducing grid congestion and enabling energy storage. However, offshore electrolysis technologies remain at early demonstration stages, and infrastructure for transport and storage is underdeveloped. High capital costs, environmental concerns, and permitting complexities further constrain progress. Dedicated strategies for hybrid offshore projects and cross-IWG governance are urgently needed.

5. Market Creation and Demand Activation

At a system level, the absence of clear demand signals and bankable business models is a critical barrier. Industries remain reluctant to absorb the green premium for renewable hydrogen, and without coordinated market-shaping instruments—such as quotas, CfDs, and public procurement policies—the risk of stranded assets persists. Aligning supply-side incentives with demand-side support is essential to unlock investment and accelerate adoption.

Strategic Imperatives
To bridge the gap between ambition and reality, the following imperatives emerge for all stakeholders and decision-makers in the European hydrogen R&I ecosystem:

- Adopt a systemic approach: Move beyond technology-centric planning to integrate policy, market, and societal dimensions. Incorporating Power-to-X strategies and hydrogen derivatives into the core framework - to enable sector coupling and flexibility – is key for the adoption of hydrogen in the different contexts of use across the regions in the MSs.
- Promote the acceleration of infrastructure development: Establish binding milestones for hydrogen pipelines, storage hubs, and refueling stations. Coordinate with the European Hydrogen Backbone and offshore grid planning to ensure timely deployment.
- Promote the strengthening of policy and regulatory frameworks: Learn from sandbox projects, harmonize permitting processes across Member States, introduce hydrogen-specific rules, and streamline administrative procedures. Embed certification schemes for renewable hydrogen to enhance market confidence.
- Promote the enhancement of funding and of risk-sharing mechanisms: Find solutions to align EU and national funding windows, leverage instruments like the European Hydrogen Bank, and introduce de-risking tools for project developers. Synchronize public aid with industrial scale-up targets under the Net-Zero Industry Act.
- Foster Market Activation: Implement demand-side measures such as CfDs, quotas, and sector-specific incentives for first-mover industries. Develop clear roadmaps for hydrogen use in steel, chemicals, and heavy transport.
- Advance Innovation and Skills Development: Support R&D for offshore electrolysis, modular electrolyser designs, and hybrid renewable systems. Launch workforce training programs and stakeholder engagement campaigns to build social acceptance and address skills gaps.
- Promote the monitoring and accountability: Introduce harmonized reporting standards, performance dashboards, and independent review mechanisms to track progress and ensure transparency.

As a final reflection, hydrogen remains a pillar of the EU's energy transition, but its successful deployment depends on urgent, coordinated action across technological, regulatory, and market dimensions. Under the new SET Plan governance, the SET Plan itself and the Hydrogen IWG's Implementation Plan must rapidly evolve from strategic vision to operational readiness in order to converge with NZIA requirements, embedding systemic approaches and near-term triggers to overcome the implementation gap. By addressing these challenges holistically—through integrated planning, robust governance, and stakeholder engagement—the EU can transform hydrogen from a promising concept into a tangible driver of climate neutrality, energy security, and industrial competitiveness.

SET4H2