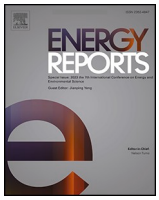
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Research paper



How to foster a resilient, efficient and clean hydrogen ramp-up – A comparative assessment of EU and US support systems

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ABSTRACT

Achieving climate targets in hard-to-electrify sectors such as energy-intensive industries, aviation and maritime requires rapid uptake of renewable and low-carbon hydrogen despite market uncertainties. However, hydrogen will contribute to decarbonization only when its production comes with zero or very limited greenhouse gas emissions. Moreover, limited public funding calls for an efficient allocation of support. Public support systems for hydrogen need to address this conundrum of greenhouse gas effectiveness, economic efficiency and resilient market uptake with a suitably designed instrument mix. A key question is how to identify ex-ante gaps and deficiencies in the instrument mix. This paper develops assessment criteria for such support systems, expanding existing assessments beyond supply-side policies and electrolytic hydrogen. The criteria are then applied to the most relevant deployment policies in the European Union, including but not limited to the Hydrogen Bank, and the United States, namely the Inflation Reduction Act and the Bipartisan Infrastructure Law. The findings indicate that the EU support system is more stringent regarding greenhouse gas effectiveness and economic efficiency than the US support system but poses greater risks to rapid market uptake due to its complexity and limited focus on domestic supply chains. The results are partially validated by recent market developments based on the IEA Hydrogen Projects Database, while the infancy of the market prevents a complete ex-post evaluation. The findings imply that the EU support system could benefit from strengthening domestic manufacturing, while the US should consider establishing a governance mechanism that enables a phaseout of fossil-based hydrogen production.

1. Introduction

The Paris Agreement aims at balancing the sources and sinks of greenhouse gases (GHG) over the course of the 21st century (UNFCCC, 2016), also referred to as "net-zero" GHG emissions. This requires an energy system dominated by renewable energy sources (RES) (IEA, 2023), in which the generation of renewable electricity and the electrification of end uses play a key role (Riahi et al., 2023). So-called hard-to-abate/hard-to-electrify sectors, such as certain energy-intensive industries, aviation and maritime transport, will still need gaseous and liquid fuels associated with zero or very limited GHG emissions (Bataille, 2020). Particularly viable options for such fuels are *low-emissions hydrogen*[1] and derivatives of this produced using RES (*renewable hydrogen*) but at least temporally also nuclear energy and other low-emission sources (*low-carbon hydrogen*), such as natural gas in combination with carbon capture and storage (CCS) (Clarke et al., 2023).

The increasing number of national hydrogen strategies emerging over the last decade demonstrates that hydrogen is considered an important building block in the transition to net-zero by many countries,

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[1] We use the term *low-emissions hydrogen* when referring to both renewable and low-carbon hydrogen, and the terms *renewable hydrogen* and *low-carbon hydrogen* to distinguish the types of production where necessary.

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including the United States of America (US) and the European Union (EU) (Ludwig-Bölkow-Systemtechnik, 2020). Due to their lead role with regard to ambition and deployment, policies in the US and the EU will be key to the successful development of a global hydrogen economy. The US, as outlined in its "National Clean Hydrogen Strategy and Roadmap", anticipates a low-emissions hydrogen (H_2) demand of 10 million tonnes per year by 2030 (U.S. Department of Energy DoE, nd). Given the country's significant RES potential, the US is expected to meet its demand for hydrogen through domestic production and may even become a hydrogen exporter. According to Hydrogen Projects Database of the International Energy Agency (IEA) as of October 2025 (IEA, nda), the projects announced for 2030 total 8.276 million tonnes H_2/y, including 0.158 million tonnes H_2/y already in operation, 0.003 tonnes H_2/y demonstration projects, and 0.652 tonnes H_2/y from projects under construction or with a final investment decision (FID), see Fig. 1 (IEA, nda). The EU, even with its more limited RES potential, still aims to produce up to 10 million tonnes of low-emissions hydrogen domestically and to import up to 10 million tonnes in 2030 (EC 2023e). As of October 2025, the projects announced for 2030 amount to 20.268 million tonnes H_2/y, including 0.118 million tonnes H_2/y that are currently operational, 0.014 million tonnes H_2/y from demonstration projects and 0.941 million tonnes H_2/y from projects under construction or at FID stage (IEA, nda).

The gap between targets and actual FIDs indicates there are substantial barriers to the market uptake of low-emissions hydrogen, in particular market failures caused by the externalized cost of fossil fuels and coordination failures caused by uncertainty about future applications and the lack of infrastructure (George et al., 2022). These are hindering investments in hydrogen production, applications and infrastructures, leading to mutually reinforcing uncertainties (Houghton and Cruden, 2011). Hence, there is a need for public support systems that go beyond subsidies (Bleischwitz and Bader, 2010) and address market failures comprehensively with a suitable instrument mix (Linares et al., 2008). Hydrogen support schemes need to ensure a *resilient uptake of both demand and supply*, i.e., schemes that are effective in spite of potential internal failures and external shocks along the supply chain (Dejonghe et al., 2023).

A resilient market uptake is not sufficient though, because hydrogen only contributes to the net-zero objective when its production achieves an *effective reduction of GHG emissions* (Bleischwitz and Bader, 2010). In 2023, however, low-carbon and renewable hydrogen made up less than one percent of global hydrogen production (IEA, 2024). Of the low-emissions hydrogen projects announced until 2030, fossil-based low-carbon hydrogen accounts for around 64 % of hydrogen production capacity in the US, but only around 6 % in the EU (IEA, ndb). Depending on the GHG intensity thresholds applied, such low-carbon hydrogen may still include retrofits of fossil-based hydrogen production with overall emissions reductions of less than 60% (Riemer and Duscha, 2023).

Currently, the US and the EU are pursuing quite different policy approaches. The hydrogen ramp-up in the US is driven mostly by a set of tax credits under the Inflation Reduction Act (IRA) (The White House, 2023a), targeting hydrogen producers and a wide variety of usages. The EU combines various types of grants, quotas and other regulatory instruments using several pieces of legislation, in particular the European Hydrogen Bank (EHB) (European Commission EC, 2023a) and the Renewable Energy Directive (RED) (European Parliament and European Council, 2023a). Both the US and the EU have multiple support policies in place (cf. Fig. 1 and details in the supplement). Since these policies interact, it would be insufficient to consider single deployment policies

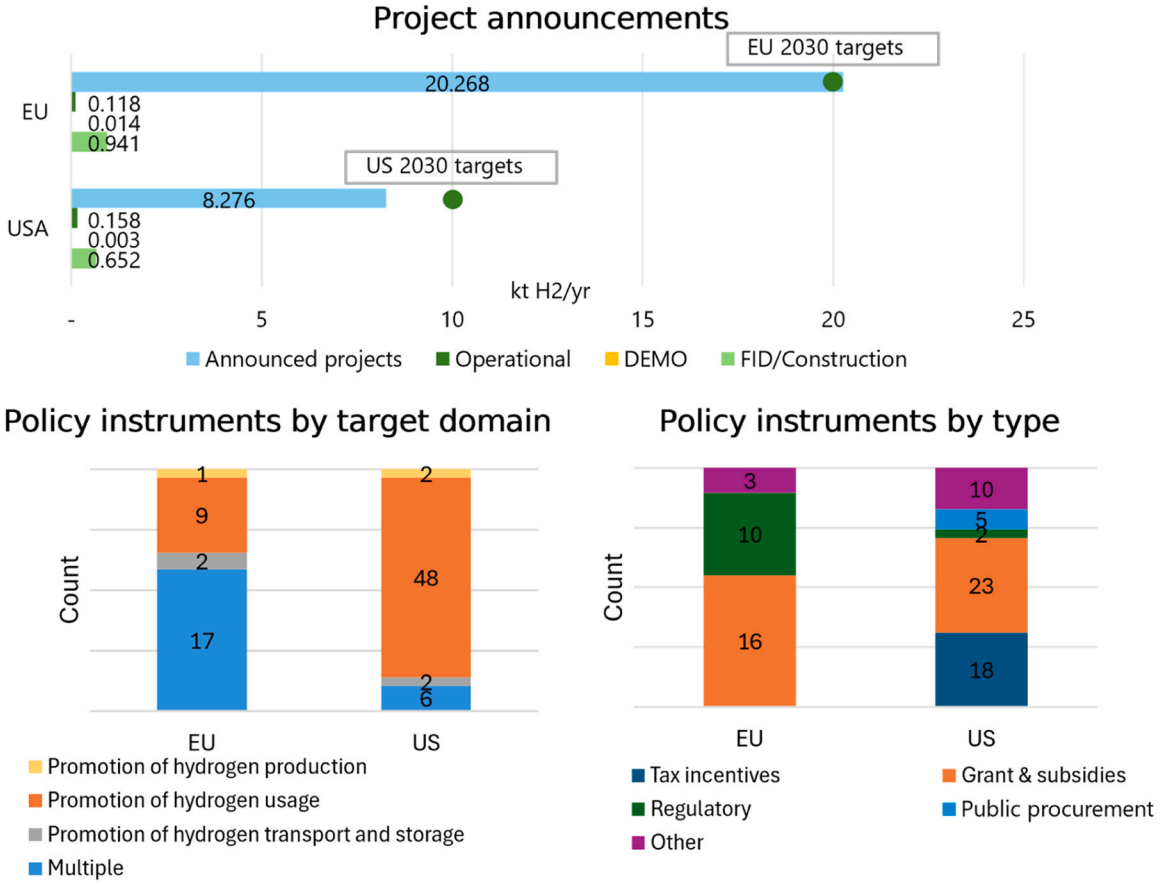


Fig. 1. EU and US hydrogen production targets, the project pipelines until 2030 (based on the IEA Hydrogen Project Database as of October 2025) and the number of policies for investment promotion by target domain and type (own evaluation).

in isolation. To improve the use of limited public funding, it is important to align the different policies to achieve an *economically efficient* allocation of support and avoid windfall profits.

The novelty of the hydrogen support systems in the EU and the US means a full ex-post assessment of their impacts is not yet possible and thus of limited value (Guillotin et al., 2025). A key question in the literature is therefore how an ex-ante assessment of different policy approaches can identify potential gaps and deficiencies in addressing market, coordination and system failures cf (Weber and Rohracher, 2012). This paper aims to contribute to this question by developing tailored ex-ante assessment criteria and applying them to the main deployment policies in the two jurisdictions.

There are comparisons of existing hydrogen support systems in the EU and the US in the academic literature, which focus on key policies such as the IRA, the EHB and the Net Zero Industry Act (NZIA) and the criteria for renewable hydrogen.

Pinto (Pinto, 2024) finds considerable differences in the overall strategy with a focus on the regulatory framework in the EU and on production incentives in the US, but similarities in the regulatory requirements for the production of electrolytic hydrogen. Penttinen (Penttinen, 2024) confirms the findings for the regulatory requirements, but also sees a convergence in production incentives. Gatto et al (Gatto et al., 2024) go beyond these analyses and use insights from the literature on analogous RES policies to plot a potential pathway from direct support to market-based incentives.

The most comprehensive assessment up to date is provided by Guillotin et al (Guillotin et al., 2025)., who compare and analyze the EU and US support frameworks based on the EHB and the IRA hydrogen production tax credit (H_2 PTC). They apply a multi-stakeholder assessment framework that evaluates these policies from the perspective of private investors, public authorities, and electricity grid operators, defining three objectives for each stakeholder group. Their analysis finds that the IRA H_2 PTC provides more efficient incentives to scale up hydrogen production than the EHB auctions, albeit at a higher overall cost (Guillotin et al., 2025).

All the comparative assessments of EU and US hydrogen support systems have two caveats in common: (1) they focus only on electrolytic hydrogen and pay little attention to fossil-based hydrogen with CCS, which is expected to remain less costly than electrolytic hydrogen (George et al., 2022) and may thus dominate the uptake of low-emissions hydrogen, depending on the design of support systems; (2) they limit the analysis to the direct support and regulation of hydrogen production (push instruments) but miss to address demand-side (pull) and infrastructure instruments (systemic) sufficiently, while the strong interactions during the market uptake call for a joint assessment. There is one report in the grey literature (Erraia et al., nd) that compares a broader instrument mix – though not systematically – and takes into account also fossil-based hydrogen, showing that the US subsidies for fossil-based low-emissions hydrogen are most effective in closing the cost gap to conventional hydrogen in spite of being lower than the subsidies for electrolytic hydrogen. Baszczenka et al (Baszczeńska et al., 2026) also point to the relevance of fossil-based low-carbon hydrogen in their broad comparison of the Norwegian and the Polish hydrogen sector.

Other studies focus mostly on the ex-ante assessment of impacts of supply-side incentives and regulation on the cost-competitiveness of low-emissions hydrogen (see, e.g., (Ueckerdt et al., 2024)) and on overall GHG emissions (see for instance (Ricks et al., 2023)). Recent literature also addresses the impact of specific criteria for procuring renewable electricity from the grid in detail (see e.g (Schlund and Theile, 2022). and (Zeyen et al., 2024) for temporal correlation and (Giovanniello et al., 2024) and (Schmidt et al., 2024) for additionality).

The analysis in this paper considers the most recent versions of the support systems in the EU and the US and goes beyond earlier analyses by considering both electrolytic and fossil-based low-emissions hydrogen and the mix of push, pull and systemic instruments. To consider the trade-offs between the *resilience of hydrogen uptake, GHG effectiveness, and economic efficiency* of support systems beyond single policies, it defines three analytically grounded assessment criteria, each explored through a set of guiding questions that enhance conceptual clarity and evaluative depth. The framework for assessing hydrogen support systems differs from that of Guillotin et al (Guillotin et al., 2025). in that it explicitly focuses on policy gaps and structural deficiencies from the perspective of policymakers. In addition, the criteria-based comparative analysis provides a broader and more detailed assessment of the respective policy support systems in the EU and the US by considering the support policies for supply, demand and infrastructure together. While the impact of the support systems is still just starting to unfold, the ex-ante assessment is complemented with an empirical analysis of the development of the project announcements and their status, as a partial validation of some of the ex-ante findings, which is raised as an important next step by both Guillotin et al (Guillotin et al., 2025) and Gatto et al (Gatto et al., 2024). This paper addresses thus a notable gap in the existing literature and provides a more comprehensive understanding of the design and effectiveness of low-emissions hydrogen support systems.

The paper starts by evaluating the literature on barriers to a market uptake of low-emissions hydrogen and deriving criteria that foster a detailed comparative assessment of hydrogen support systems in terms of these barriers and potential trade-offs (Section 2). It then provides an overview of the hydrogen support systems in the EU and the US (Section 3). The assessment criteria are applied to selected deployment instruments in both economies, potential gaps and deficiencies are discussed and partially validated with a view to current market dynamics (Section 4). Finally, conclusions are drawn on the current EU and US hydrogen support systems and implications are derived for future adjustments of the instrument mixes (Section 5).

2. Formulation of the assessment framework

This section explains the need for hydrogen support systems, develops the criteria for their assessment and describes how they are applied to hydrogen support systems.

2.1. Rationale and assessment criteria for hydrogen support systems

Various uncertainties and barriers to a global hydrogen economy can be identified from the literature. Developing global hydrogen markets implies the simultaneous ramp-up of supply, demand and infrastructure (“three-sided chicken and egg problem”) and represents a massive coordination challenge. This requires public support systems to address the related market, coordination and system failures, including infrastructure needs (Guillotin et al., 2025), and to combine technology-push policies, such as production tax incentives, or feed-in tariffs, with demand-pull policies, such as carbon pricing or hydrogen quotas (Aflaki et al., 2021). The cost gap to unabated fossil alternatives is a major barrier impeding the ramp-up of low-emissions hydrogen (Longden et al., 2022). In the long term, technological learning in combination with increased carbon pricing may close this gap (Ueckerdt et al., 2024). Recent developments, however, are expected to increase the cost gap and hence the need for public support, namely inflationary pressures affecting capital and financing costs, together with a recovery of lower natural gas prices (IEA, 2024). Another barrier concerns the high costs of electrolyzers and the uncertainty surrounding their future cost reduction potential (Jesse et al., 2024). Relatedly, incomplete markets for GHG externalities can cause additional barriers (Farrell, 2023). Furthermore, uncertainties about future natural gas and electricity prices translate into cost uncertainties about low-emissions hydrogen prices (Joy and Al-Zaili, 2021). Next, market characteristics will determine price formation. For instance, imperfect competition and lack of transparency would allow suppliers to set price markups (Wietschel et al., 2021). High price levels for low-carbon hydrogen are particularly expected in the

short term when supply is inelastic (Farrell, 2023).

The lack of infrastructure is a common system failure in sustainability transformations (Weber and Rohracher, 2012), and a central obstacle to successful market uptake. This concerns both hydrogen-related infrastructure, such as terminals or pipelines, and renewable energy infrastructure. A lack of clear policy signals and regulation can further delay hydrogen uptake (IEA, 2024). For instance, specifying the definition of low-emissions hydrogen and establishing its certification is crucial to facilitating trade (Abad, 2020).

Different criteria must be weighed against each other when designing and assessing policy schemes to overcome these barriers. Bleischwitz et al (Bleischwitz, 2010) argue that a hydrogen support scheme must balance market requirements, sustainability/climate requirements and hydrogen technology deployment. This requires *resilient hydrogen uptake* in the sense of Gatto and Drago (Gatto and Drago, 2020), who define resilience "as the adaptive capacity of improving performance, as a result of learning and adaptation, informed by continuous change".

While rapid market uptake is desirable, the climate mitigation impact of hydrogen depends on how it is produced and whether it can be directed at applications where alternatives such as direct electrification are not available (van Renssen, 2020). Therefore, GHG effectiveness emerges as a key assessment criterion for the design of support schemes. At the same time, public budget constraints require support schemes to focus on the most important market failures (Farrell, 2023). In this regard, policy assessments usually evaluate the instrument's economic efficiency, i.e., whether the policy objective is achieved at minimum cost, whereby the social costs of supporting hydrogen should not exceed the social benefits (Jenkins, 2014).

Accordingly, the comparative assessment of hydrogen support systems presented here focuses on the criteria related to *economic efficiency, environmental effectiveness and resilient market uptake*. These three criteria make it possible to discuss key trade-offs, for instance, with regard to the usefulness of local content requirements for market development cf (Probst et al., 2020) and the transitional role of fossil-based hydrogen production with carbon capture and storage (van Renssen, 2020).

2.2. Indicators for assessing the key deployment policies

Given that the impact of the instrument mix cannot be observed yet, all three criteria are assessed by evaluating the design of the individual instruments in the mix and synthesizing the findings across the various policies. A set of key indicators derived in the following subsections is used to identify relevant design aspects within the policy content. Since the assessment criteria are broad, the key indicators focus on the most critical implications for each criterion, enabling a structured and targeted assessment of the respective policies.

These indicators are used to identify the most relevant deployment policies (*cornerstone instruments*) and their most relevant provisions for each of the criteria. This basis is used to compare the EU and US approaches and identify potential policy gaps and deficiencies. These potential gaps and deficiencies do not necessarily imply the need for change, but can inform policymakers and researchers where to carefully evaluate the successfulness of the support systems. The guiding questions for the comparative assessment of the key indicators are listed in the supplementary material.

2.2.1. Resilience of hydrogen uptake

The key indicators A1-A4 for the *resilience of hydrogen uptake* address how the support system intends to ensure that hydrogen uptake meets strategic targets and contributes to the development of a robust and stable hydrogen market despite distortions due to deep market and supply uncertainties. In particular, this requires mechanisms to align demand, supply, transport and storage infrastructure development (A1, cf (Gatto and Drago, 2020).). Imbalances between domestic off-takers and producers can be compensated by establishing markets and infrastructure for imports and exports (A2, cf (Carlson et al., 2023). A certain level of domestic production can increase resilience by reducing the uncertainty due to the lack of established international markets and supplier dependencies. A key indicator in this regard is the incentivized share of both domestic hydrogen production (cf (Quitzow et al., 2024).) and manufacturing capacities (cf (Wachsmuth et al., 2024).) for the required plants (A3). A diversity of supply options also reduces the reliance on single suppliers, mitigates the risk of supply disruptions, and may decrease uncertainties about the domestic uptake of production (A4, cf (Dejonghe et al., 2023).).

2.2.2. GHG effectiveness

A key rationale for providing public support for low-emissions hydrogen is to reduce GHG emissions, given the lack of incentives for private actors to compensate for such negative externalities (Weber and Rohracher, 2012). The corresponding key indicators B1-B4 are thus intended to capture to which extent the production and use of hydrogen contribute towards to meeting the GHG targets. In particular, the targeted level of emission intensity and additional requirements for the use of renewable electricity are key indicators for ensuring sufficient GHG emissions avoidance (B1, cf (Ricks et al., 2023).). The GHG effectiveness is also linked to the eligible types of hydrogen production, for instance, the role of fossil-based hydrogen production with carbon capture (B2, cf (Longden et al., 2022).), and to the eligible types of applications, for instance, hydrogen is less effective in those with direct electrification options (B3, cf (Wachsmuth et al., 2024).). Mechanisms to avoid fossil lock-ins must be established to achieve GHG neutrality in the long term (B4, cf (Farrell, 2023).).

2.2.3. Economic efficiency

The key indicators for *economic efficiency* C1-C4 address how support policies ensure that public funds are used cost-effectively to achieve their objective, e.g., by mechanisms allocating subsidies to the most efficient producers or users (C1, cf (Anatolitis et al., 2022).). The indicator C2 addresses whether financial support mechanisms ensure that public financial incentives do not exceed the levels required to catalyze investment (cf (Houghton and Cruden, 2011).) and avoid the generation of rents by private actors (cf (Köveker et al., 2023).). Costs to hedge against market risks can be comparatively high for undeveloped markets. It is therefore relevant to examine how support mechanisms address these economic risks and uncertainties (C3, cf (Richstein and Neuhoff, 2022).). Weighing up the support schemes' social costs and benefits also needs to consider the administrative costs for private and public actors (C4, cf (Wachsmuth et al., 2021).).

There are trade-offs between the different assessment criteria, and one instrument can affect more than one criterion. The instrument mix may not be aligned or homogeneous with respect to the individual criteria, which may jeopardize the expected impacts.

2.3. Validation of ex-ante assessments by evaluation of market development

The ex-ante assessment of the content of support policies is contrasted by an empirical evaluation of market developments in Section 4.5, using project-level data from the IEA Hydrogen Projects Database and complementing grey literature. While hydrogen supply developments are assessed for the period 2022–2025, infrastructure developments are examined for the period 2024–2025. The data is used to track recent developments in announced hydrogen production and infrastructure projects in the EU and the US by production pathway and project maturity. This analysis does not constitute an ex-post evaluation of policy effectiveness but serves as a validation of selected ex-ante findings by examining whether observed project dynamics and support costs are broadly consistent with the incentives embedded in the respective support systems.

3. Hydrogen support systems in the US and the EU

This section provides a brief overview of the targets and cornerstone instruments of the respective hydrogen support systems in the EU and the US published until the end of the year 2025. This is complemented by quantitative data on the current mix of policy instruments, information about the identification of the cornerstone instruments, and an in-depth assessment of the key indicators for each of the cornerstone policies in the supplementary material.

3.1. EU policies

The EU hydrogen strategy was launched in 2020, aiming to produce up to 1 million tonnes of renewable hydrogen by 2024 and 10 million tonnes of renewable hydrogen production by 2030 (European Commission EC, 2020). In May 2022, the REPowerEU Plan introduced the additional ambition to import 10 million tonnes of hydrogen by 2030, doubling the EU's ambition with regard to renewable hydrogen (European Commission EC, 2022). Finally, in May 2024, the EU adopted the NZIA, seeking to ensure that 40 % of the EU's annual deployment need for net-zero technologies are manufactured domestically by 2030, which includes electrolyzers and fuel cells (European Commission EC, 2023c). The intentions behind the EU Hydrogen Strategy and REPowerEU are manifold, combining the goals to reduce domestic GHG emissions and the dependency on natural gas with assuming global leadership in hydrogen technologies. To achieve these goals, the European Commission (EC) has implemented a mix of regulations and funding schemes along the hydrogen value chain. Details on the respective policies are provided in Table 1.

A key instrument on the demand side is the introduction of quotas for certain hydrogen-based renewable fuels, referred to as Renewable Fuels of Non-Biological Origin (RFNBO). The RED introduces a combined advanced biofuels and RFNBO quota in the transport sector and a RFNBO quota for hydrogen use in industry, both by 2030) (European Parliament and European Council, 2023a). Implementing these targets is the responsibility of the Member States.The ReFuel EU Aviation initiative introduces additional quotas for so-called sustainable aviation fuels, applicable directly to the firms supplying aviation fuels in the EU (European Parliament and European Council, 2023b). These include subtargets for hydrogen-based kerosene. Finally, in the maritime sector, the FuelEU Maritime Regulation (European Parliament and European Council, 2023c) introduces an indicative RFNBO target for 2031 and, if that is not achieved, a binding target for 2034.

For hydrogen-based fuels to qualify as RFNBO or low-carbon hydrogen, the EC has established the joint requirement that they need to reduce GHG emissions by 70% with regard to a fossil comparator (this translates into the 3.38 kg carbon dioxide equivalent ($CO_{2\ eq}$)/kg H_2 emission threshold) in the RED (European Parliament and European Council, 2023a) and the Hydrogen and Decarbonised Gas Market Directive (European Parliament, European Council, 2024). For RFNBOs, two so-called delegated acts to the RED (Delegated Act 2023/1184 and Delegated Act 2023/1185) provide detailed methodologies for determining GHG emissions and when grid electricity used for hydrogen production can be counted as renewable (European Parliament and European Council, 2023a). The latter methodology stipulates that the consumed electricity should be from additionally constructed renewable power plants within the same bidding zone (or a neighboring one under certain conditions) and with temporal correlation of supply and consumption. Following a phase-in period, these criteria form the basis for receiving any funds from EU support schemes, and for accountability under the RED quotas and the EU emission trading system (EU ETS). For low-carbon hydrogen, in particular nuclear and abated fossil-based hydrogen, the Commission published a delegated act in July 2025 containing a methodology to calculate GHG emissions savings with additional requirements for methane leakage and CCS, but no requirements with regard to additionality, geographical and temporal correlation (European Commission EC, 2025a).

Table 1
Overview of the key EU hydrogen support policies[a].

Instrument	Description
Quotas	
Transport (REDIII)	• Combined biofuels and RFNBO quota of 5.5% (minimum of 1% RFNBO) by 2030
Industry (REDIII)	• RFNBO quota: 42% in industry by 2030, 60% by 2035
Aviation (ReFuel EU Aviation Initiative)	• Sub-target of 1.2% synthetic aviation fuel (hydrogen-based kerosene) by 2030–2031, 5% in 2035, 35% by 2050
Maritime (FuelEU Maritime Regulation)	• 1% RFNBO target by 2031; if not achieved, 2% target by 2034
Definition of renewable fuels of non-biological origin (RFNBOs; including hydrogen)	• 3.38 kg $CO_{2\ eq}$/kg H_2 emission threshold • Additionality of RES: entering into operation less than 3 years earlier • Temporal correlation with RES production: monthly until 1 January 2030; hourly thereafter • Spatial correlation with RES production: within the same bidding zone
Definition of low-carbon gases	• 3.38 kg $CO_{2\ eq}$/kg H_2 emission threshold • Incl. nuclear- and fossil-based hydrogen with special treatment of methane leakage • No requirements for additionality, spatial and geographical correlation
EU Innovation Fund (IF) grants	• Funding program for the demonstration of innovative low-carbon technologies
European Hydrogen Bank (EHB)	• Production subsidy for domestic production of renewable and low-carbon electrolytic hydrogen: Fixed premium paid per kg of renewable hydrogen • Subsidy for hydrogen imports not yet implemented
Carbon Contracts for Difference (CCfDs, not yet implemented)	• Compensation of the difference between the CO_2 abatement costs and the current CO_2 reference price for industry decarbonization
Trans-European Networks for Energy (TEN-E)	• Sets out the process for selecting Projects of Common Interest (PCI) eligible for funding under the Connecting Europe Facility (CEF) – Energy • Allocated €5.8 billion funding from 2021 to 2027
Important Projects of Common European Interest (IPCEI)	• IPCEI status makes projects eligible for state aid • 4 IPCEIs have been launched (122 projects in 16 countries with €18.9 billion investment support)

[a] CO2 = carbon dioxide, CO2 eq = carbon dioxide equivalent, RFNBO = Renewable Fuel of Non-Biological Origin

The EU Innovation Fund (IF) (European Commission EC, 2023b), financed by revenues from the EU ETS, has awarded over €2 billion of grants to hydrogen-related projects until 2025. The domestic leg of the EHB, also financed by the IF, provides a fixed premium to producers per kilogram of renewable hydrogen produced via competitive auctions (European Commission EC, 2023a), with the second auction including a window dedicated to maritime offtakers and limitations to the procurement of non-EU electrolyzer components. The first two auctions awarded about €1700 million to projects under the general window and about €100 million to projects under the maritime window. In December 2025, the EC published the terms and conditions for the third auction round: this time, the auction consists of three baskets. One is dedicated to RFNBO with a budget of €600 million, RFNBO and/or low-carbon electrolytic hydrogen with a budget of €400 million, and one is for hydrogen and derivatives for maritime and aviation off-takers within the EEA with a budget of €300 million. The EHB also plans to enable joint European auctions for hydrogen imports under the EHB (European Commission EC, 2023a) but its implementation is still pending, partly due to the lack of a dedicated EU budget. The EU ETS regulation

(European Parliament and European Council, 2023) also allows the EC to subsidize the use of hydrogen via so-called Carbon Contracts for Difference (CCfDs), which hedge against carbon price risks and other potential price risks (cf (Richstein et al., 2024).). The Industrial Decarbonisation Bank, announced under the Clean Industrial Deal in February 2025 (European Commission EC, 2025b), has since moved into implementation. Its first pilot auction, with a budget of €1 billion, supported the decarbonisation of industrial process heat but explicitly excluded the use of hydrogen (European Commission EC, nd). The further implementation of the Industrial Decarbonisation Bank is expected to cover also hydrogen applications, possibly in the form of CCfDs.

The development of an interconnected European hydrogen grid is supported by the EU policy of Trans-European Networks for Energy (TEN-E), which includes 65 so-called Projects of Common Interest (PCIs) along three hydrogen corridors (European Commission EC, 2024). PCIs benefit from expedited permitting procedures and can apply for financial assistance from the Connecting Europe Facility (CEF) for Energy (European Parliament, European Council, 2021). In addition to the main EU-level schemes outlined above, the EU makes a number of exceptions to its tight restrictions on the provision of state aid by Member States based on the scheme for supporting so-called Important Projects of Common European Interest (IPCEI) (European Parliament and European Council, 2023) as well as the Temporary Crisis and Transition Framework (European Commission EC, 2023d).

3.2. US policies

As outlined in its Hydrogen Strategy and Roadmap, the US aims to achieve 10 million tonnes of domestic clean hydrogen production with an emission intensity of less than 2 kg $CO_{2\ eq}$/kg H_2 per year by 2030 at $1/kg and more than 50 million tonnes by 2050 (U.S. Department of Energy DoE, nd). It also aims to have 3 gigawatts (GW) or more electrolyzer manufacturing capacity per annum in the US by 2028 and plans to export hydrogen, but has not yet defined an official export target (U.S. Department of Energy DoE, nd).

The Biden administration launched a set of policies to scale up domestic hydrogen production and use across multiple sectors with a strong focus on financial incentives to stimulate the economy and create jobs. The Bipartisan Infrastructure Law (BIL) and the IRA were the central pillars of this approach and have catalyzed $8 billion of investments in low-emission hydrogen supply (Bermel et al., 2024) (as of June 2024), see Table 2 for a detailed breakdown. Since January 2025, the second Trump administration's efforts to reverse parts of the clean energy policies enacted by the Biden government have triggered uncertainty in the hydrogen sector.

The IRA fosters the production of hydrogen via extensive tax credits (The White House, 2023a). The central supply-side scheme is the H_2 PTC, which offers a production tax credit (granting a fixed credit per kilogram of produced hydrogen) or an investment tax credit (granted for a fraction of their capital expenses). These tax credits can be combined with additional credits for renewable energies in the case of renewable hydrogen production. A Bonus Credit Amount includes 5 times the base amount if the facility meets prevailing wage and registered apprenticeship requirements. The resulting credit varies based on the carbon intensity of hydrogen production (The White House, 2023a). The final rules specifying the eligibility criteria for the H_2 PTC were published in January 2025. For electrolytic hydrogen, these criteria include temporal matching, deliverability and incrementality similar to the criteria of additionality and temporal and geographical correlation in the EU (see Section 3.1). The final rules are more flexible and technology-neutral than the April 2024 draft. They now include eligibility for tax credits for electricity from nuclear and CCS-equipped generators under certain conditions. Additionally, the hourly temporal-matching requirement for the generation and consumption of electricity has been postponed from 2028 to 2030 (U.S. Department of Treasury. nd.). The Trump administration has enacted the One Big Beautiful Bill Act (OBBBA) (Public Law

Table 2
Overview of the key US hydrogen support policies.

Instrument	Description
Inflation Reduction Act (IRA)	
H_2 PTC[a]	• Production tax credit or investment tax credit based on the carbon intensity of hydrogen production for facilities that begin construction before January 1, 2028
	Kg CO_2/kg of hydrogen / Production tax credit per kg of H2 / Investment tax credit in %
	< 0.45 / $3.00 / 30%
	< 1.5 / $1.00 / 10%
	< 2.5 / $0.75 / 7.5%
	< 4.0 / $0.6 / 6%
Definition of clean hydrogen (final regulation)	• Temporal matching: Annually until 2030, hourly thereafter • Deliverability: Electricity production in the same balancing region or physical delivery to H_2 production region with transmission rights and hourly tracking • Incrementality: Commissioning or uprate (capacity increase) no more than 3 years before the H_2 production facility. Specific exemptions: qualifying nuclear reactors, CCS-retrofitted plants, or plants in states with strong electricity decarbonization and GHG cap program
Carbon Oxide Sequestration Tax Credit[3]	• Base credit: $17/tonne of qualified carbon oxide, adjusted annually for inflation • OBBBA establishes parity in the credit amount for secure geological storage, enhanced oil recovery, and utilization for facilities or equipment placed in service after July 4, 2025 • Cannot be stacked with H_2 PTC
Advanced Energy Project Credit	• Funding for manufacturing projects producing fuel cell electric vehicles, hydrogen infrastructure, electrolyzers, other products • $10 billion for eligible projects • OBBBA prevents further increase of the program's funding allocation
New Clean Vehicle Credit[b]	• Up to $7500 per vehicle for purchasers of clean vehicles (incl. fuel cell vehicles) • Final assembly in US and need to meet critical mineral requirements
Clean Fuel Production Credit[3]	• $0.20/gallon for domestic production of clean transportation fuels, including sustainable aviation fuels, that emit less than 50 kg of CO_2 per mmBTU compared to petroleum-based jet fuels • Feedstock needs to origin from the US, Canada or Mexico • Special higher credit rates for sustainable aviation fuel were eliminated for fuel produced after December 31, 2025
Sustainable Aviation Fuel Credit[c]	• $1.25 per gallon for sale or use of sustainable aviation fuels
Alternative Fuel Refueling Property Credit[d]	• For alternative fuel vehicle refueling and charging property of up to $100,000 in low-income and rural areas including electricity, ethanol, natural gas, hydrogen, biodiesel, and others
Bipartisan Infrastructure Law (BIL)	
Promotion of Regional Hydrogen Hubs	• $7 billion in funding for development of 7 regional clean hydrogen hubs • $1 billion to clean hydrogen electrolysis program, $500 million to incentivize clean hydrogen manufacturing and recycling
Industrial Demonstrations Program (IRA & BIL)	• $6.3 billion in funding for projects focusing on hard-to-abate industries • OBBBA rescinds the unobligated balance of the IRA
Advanced Technology Vehicles Manufacturing (ATVM) Loan Program (IRA & BIL)	• Loans for domestic production of electric vehicles (incl. fuel cell electric vehicles)

[a] As amended by OBBBA
[b] Terminated by the OBBBA for vehicles acquired after September 30, 2025
[c] Terminated by the OBBBA for sales or uses after September 30, 2025
[d] OBBBA accelerated termination of the credit to June 30, 2026

119–21), which terminates the Section 45 V Clean Hydrogen Production Credit for facilities whose construction begins after 31 December 2027. The OBBBA was enacted in July 4, 2025. Meanwhile, a deadline has expired before which the Trump administration could have challenged the existing hydrogen tax credit rules (U.S. Congress, 2025).

The Carbon Oxide Sequestration Tax Credit, which was retained and modified under the OBBBA, provides a parallel incentive for investment in low-carbon hydrogen, offering a base credit per tonne of carbon dioxide captured and sequestered, while prohibiting cumulation with the H_2 PTC (U.S. Congress, 2025; Internal Revenue Service IRS, 2026). The Advanced Energy Project Credit (AEPC) is a tax credit for project-level investments, including the production of electrolyzers, hydrogen infrastructure, and a range of other products (The White House, 2023a). Until September 30, 2025, the New Clean Vehicle Credit (IRA) subsidized the purchase of battery-electric vehicles and fuel-cell electric vehicles (FCEVs) (The White House, 2023a). The Clean Fuel Production Credit (IRA) offers tax credits for domestic production of clean transportation fuels, based on their lifecycle greenhouse gas emissions. Under the OBBBA, the credit was extended through December 31, 2029, while transportation fuels produced after December 31, 2025, must be derived exclusively from feedstock produced or grown in the United States, Mexico, or Canada (The White House, 2023a). The OBBBA also eliminated the special higher credit rates for sustainable aviation fuel for fuel produced after December 31, 2025 (U.S. Congress, 2025). The Sustainable Aviation Fuel Credit (IRA) provided a credit for the sale or use of sustainable aviation fuel, which must be produced in the US (The White House, 2023a), but was eliminated by the OBBBA after September 30, 2025. SAF production, however, remains eligible for the Clean Fuel Production Credit, subject to the general §45Z credit rates and requirements (U.S. Congress, 2025). The Alternative Fuel Refueling Property Credit (IRA) provides a credit for alternative fuel vehicle refueling and charging property in low-income and rural areas, including hydrogen (The White House, 2023a). However, the OBBBA shifted the termination date of the credit from December 31, 2032, to June 30, 2026 (U.S. Congress, 2025).

Beyond the IRA, the BIL provides $7 billion in funding for the development of seven regional clean hydrogen hubs, $1 billion for a clean hydrogen electrolysis program, and $500 million to incentivize clean hydrogen manufacturing and recycling (The White House, 2023b). The IRA and BIL also fund a $6.3 billion Industrial Demonstrations Program (U. S. Department of Energy DoE, 2026a), which awarded $1.7 billion to 33 projects in March 2024 for hydrogen-based decarbonization technologies in sectors like steel and chemicals (Hydrogen Insight, 2024). However, the OBBBA rescinded the unobligated balance of the IRA statutory authority underlying the program. The U.S. Department of Energy announced in 2025 the termination of 223 previously awarded clean-energy demonstration projects nationwide (representing over $7.5 billion), a subset of which reportedly affected the hydrogen-related awards (U. S. Department of Energy DoE, 2026b).

4. Comparative assessment of the EU and the US

This section applies the three assessment criteria to the instruments of the EU and US hydrogen support systems identified in Section 3: (1) *resilience of hydrogen uptake*, (2) *GHG effectiveness*, and (3) *economic efficiency*. An extensive list with an in-depth assessment of all policies for both the EU and the US is provided in the supplementary material to this paper. The following subsections synthesize the findings for each criterion referencing the associated key indicators derived in Section 2.2, and referring to the policy instruments without repeating the references.

4.1. Resilience of hydrogen uptake

The deployment policies and their provisions most relevant to the *resilience of hydrogen uptake* listed in Table 3 show how the support systems in the EU and the US intend to avoid system and coordination failures and to ensure that hydrogen uptake reaches the strategic targets in spite of deep market and supply uncertainties. The EU addresses the need to avoid system failures and secure resilient hydrogen uptake, in particular by fostering the creation of domestic markets via EU-wide infrastructure development, demand-side quotas, and a supply strategy, but provides only limited supply-side support (A1). However, the EU has not yet implemented the announced demand-side support scheme (CCfDs) and import auctions, which may impair the achievability of the demand-side quotas and import targets (A4).

The US has an uncapped support for hydrogen production and investments in offtakers but no instruments to avoid coordination failures, and it remains to be seen whether the hydrogen hubs are realized and can drive the development of regional transport infrastructures and markets. There is a much stronger focus in the US on the domestic production of hydrogen and manufacturing of electrolyzers. This approach not only supports the domestic economy but also increases the resilience to external supply risks in the upstream value chain (A3). Although the EU has begun to initiate similar activities via the NZIA, the IF grants and the limitations to non-EU procurement of electrolyzer components under the EHB, so far, there is no budget explicitly dedicated to the domestic manufacturing of electrolyzers.

While the EU aims at imports and the US at exports, neither has a clear strategy for import and/or export infrastructures (A2), which risks coordination failures in case of domestic market distortions.

Table 3
Key aspects of EU and US hydrogen support systems: Resilience of hydrogen uptake.

Resilient H_2 uptake	EU	US
Strategic targets most relevant for resilient hydrogen uptake	• Targeted 50% share of domestic supply and imports (REPowerEU). • 40% of electrolyzers and fuel cells are to be manufactured domestically (NZIA)	• General ambition to become an exporter (US H_2 strategy) • Since no import target, implicit target of 100% domestic production.
Most relevant deployment policies	• NZIA, Gas Market Package, RED • EHB, IF grants, TEN-E	• IRA H_2 PTC and AEPC • BIL H_2 hubs
Most relevant provisions of the deployment policies	• Gas Market Package fosters creation of non-discriminatory markets and infrastructures and EU-wide network development plan • RED III establishes a strategy for renewable H_2 supply and quotas for demand sectors • EHB and IF grants have limited budgets; IF grants support domestic manufacturing; EHB partially excludes non-EU manufacturing.	• IRA tax credits are uncapped, support local manufacturing of electrolyzers, provide additional funding for renewables based on local content requirements and partly require domestic procurements. • Selection of BIL H_2 hubs considers diversity in regions and actors.
Potential gaps and deficiencies	• No dedicated scheme for import/export infrastructures, although some are prioritized with a focus on ammonia imports (TEN-E). • No dedicated budget for supporting demand and domestic manufacturing (IF grants, EHB). • Import auctions not implemented due to the lack of a dedicated budget (EHB)	• No instruments for matching demand and supply beyond regional alignment within BIL H_2 hubs. • No policy mechanism for creating import/export infrastructures. • No safeguards in addition to localization of production and manufacturing (IRA).

4.2. GHG effectiveness

The most relevant instruments and provisions for *GHG effectiveness* listed in Table 4 are used to deduce how much the production and use of hydrogen can be expected to contribute to meeting climate targets. While the EU prioritizes non-fossil-based hydrogen, e.g., limiting the EHB to renewable and low-carbon electrolytic hydrogen, both the EU and the US support systems are open to renewable, nuclear- and fossil-based low-emissions hydrogen (B2), as long as the well-to-gate GHG emission intensity is below a certain threshold. While the EU applies these thresholds also in the RFNBO quotas and for hydrogen-based low-carbon fuels under the EU ETS, the US make no use of the thresholds in instruments other than the IRA PTCs.

The methodology for GHG accounting of fossil-based low-carbon hydrogen in the EU ensures that the specific upstream methane emissions must be reported and taken into account to meet the 70% threshold. Moreover, the 70% threshold already set in the Gas Market Package excludes the retrofit of existing natural gas-based hydrogen production with CCS of process emissions only (cf (Riemer and Duscha, 2023).). While the lower end of the IRA thresholds in the US is more ambitious than the EU threshold, the higher end of 4 kg CO_2eq/kg H_2 is less stringent (B1). According to Salkuyeh et al. (2017), the official US life cycle model leads to 3.9 kg CO_2eq/kg H_2 for fossil-based hydrogen with CCS, which suggests that the threshold was chosen to include these. The US system might thus not sufficiently address market failures as it supports low-carbon hydrogen production not compatible with the US long-term objective of climate neutrality and having no mechanism for its phase-out. The EU's RFNBO quotas are a mechanism that might help to phase out fossil-based hydrogen but these need to be extended to all sectors to avoid a shift to the power sector, for instance (B4).

Both the EU and the US intend to use similar criteria for the use of grid electricity (B1), although stakeholder concerns have delayed the tightening of the EU's rules. Both the US and the EU employ a phased approach, starting with monthly temporal correlation combined with additionality requirements and switching to hourly correlation later. Zeyen et al. (2024) find that even annual temporal matching can effectively limit emissions if cheap storage is available and electrolysis is operated flexibly, while Ricks et al. (2023) emphasize that hourly correlation combined with additionality is essential to reducing emissions. The EU applies the criteria for procuring renewable electricity from the grid also to imports. Schmidt et al. (2024) argue that the additionality rule could inadvertently increase global emissions, as new hydrogen production capacity could compete with local decarbonization efforts due to short-term economic constraints and the limited availability of labor required to build renewable energy infrastructure. They recommend restricting hydrogen imports to countries with a strict cap on CO_2 emissions from the power sector, which the EU could consider when designing the pending import leg of the EHB.The US prioritizes the use of hydrogen and derivatives across various modes in the transport sector, risking that low-emissions hydrogen is not available to hard-to-abate sectors due to higher willingness to pay of, for instance, passenger vehicles (B3). The EU has a greater focus on industry and addresses the hard-to-abate uses in the transport sector with quotas. So far, there is no financial support for hydrogen use in such sectors, except for a dedicated budget for the maritime sector in the second EHB auction round. This suggests that EU Member States may fail to reach the ambitious RED industry quota.

Table 4
Key aspects of EU and US hydrogen support systems: GHG effectiveness[a].

GHG effectiveness	EU	US
Strategic target(s) most relevant to GHG effectiveness	• 10 million tonnes of domestic *renewable hydrogen* production with life-cycle emissions of • < 3.38 kg $CO_{2\ eq}$/kg H_2 per year by 2030	• 10 million tonnes of domestic *clean hydrogen* production with life-cycle emissions of < 2 kg $CO_{2\ eq}$/kg H_2 per year by 2030
Most relevant deployment policies	• Emissions Trading System (EU ETS) • Gas Market Package, RED and delegated acts • EHB, Carbon Contracts for Difference (CCfDs)	• IRA H_2 PTC, AEPC, and CCSTC
Most relevant provisions of the deployment policies	• Hydrogen and derivatives are accounted as zero-emissions fuels under EU ETS, as long as life-cycle emissions are < 3.38 kg $CO_{2\ eq}$/kg fuel. • EHB support focused solely on non-fossil-based hydrogen, RED III includes quotas for renewable hydrogen in industry and transport • RED III quotas and EHB support require additionality, geographical and monthly temporal correlation of RES-E supply (hourly after 2029)	• IRA H_2 PTCs staged by carbon intensity: from \$0.6 for emissions < 4 kg CO_2/kg H_2 to \$3 for emissions < 0.45 kg CO_2/kg H_2 • Electricity-based hydrogen requires additionality, geographical and monthly temporal correlation of RES-E supply (hourly after 2029) with an exemption for nuclear • Other IRA tax credits establish specific subsidies for production of transport fuels and certain applications such as fuel cells.
Potential gaps and deficiencies	• No subsidies for use in certain sectors so far (CCfDs), except for a share dedicated to the maritime sector under the EHB. • No general quota for non-fossil hydrogen	• Hydrogen with CCS limited to process emissions may benefit from IRA H_2 PTCs. • No mechanism to phase out fossil-based hydrogen to achieve GHG neutrality

[a] RES-E = renewable electricity

4.3. Economic efficiency

The most relevant instruments and provisions for *economic efficiency* listed in Table 5 clarify how support policies in the EU and the US intend to ensure that public funds are used cost-effectively. The EU puts a lot of effort into achieving an efficient allocation of its funds. This applies to the EHB, in particular, where funds are auctioned with the bid price as the sole award criterion. In contrast, the US H_2 PTC is fixed and open to all producers starting production before the end of 2027, and does not include any mechanism for the efficient allocation of public funds (C1). The same applies to the other IRA tax credits as well as the BIL hydrogen hubs. The effort required to implement the EU schemes is comparatively high due to the multi-focused goals and complex rules. This carries the risk that producers and users may relocate to non-EU countries (C4). The easy-to-access US support system can be expected to mobilize substantial investments but demonstrates limited governance of a targeted use of funds and risks overfunding producers once the need for funding declines (C2).

Looking at the economic efficiency to avoid additional power-sector emissions, the scientific literature suggests that there are more efficient ways than implementing hourly temporal correlation, such as providing subsidies for carbon-free energy (cf (Ruhnau and Schiele, 2023).). Brandt et al. (2024) find that unrestricted grid electricity use for green hydrogen can lower costs without necessarily increasing GHG emissions compared to grey hydrogen, but may also create incentives for much higher emissions under low electricity prices. Hordvei et al. (2025) find that additionality is the most expensive criterion, increasing expected EU system costs by €82 billion (2024–2048), but also the most effective in accelerating renewable energy deployment.

The US should consider this when revising the IRA H_2 PTC, and the EU might consider this in the upcoming review of the delegated act to the REDIII. Richstein et al. (2024) point out that hedging against additional economic risks, such as varying electricity prices, may lead to more efficient schemes. This issue is not addressed by either the US or

Table 5
Key aspects of EU and US hydrogen support systems: Economic efficiency.

Economic efficiency	EU	US
Target(s) most relevant to economic efficiency	• Cover and eventually lower the cost gap btw. renewable hydrogen and fossil fuels (EHB)	• Achieve domestic clean hydrogen production at \$1/kg H_2 by 2030 (US H_2 Strategy)
Deployment policies	• EU ETS, EHB, IF grants, CCfDs	• IRA H_2 PTC, AEPC, and CCSTC
Most relevant provisions of the deployment policies	• EHB grants support based on auctions, which has resulted in support of < EUR 0.5/kg H_2 • EHB support excludes cumulation with other funds, while IF grants and frameworks for national schemes limit cumulation to cover the funding gap and try to leverage private funding	• IRA tax credits granted to all producers satisfying the conditions with low burden on both administration and producers. • Renewable hydrogen can profit from stacking of H_2 PTCs and AEPCs, while stacking H_2 PTCs with COSTCs is excluded
Potential gaps and deficiencies	• Lower importance of cost efficiency under schemes other than the EHB (IF grants). • Under current schemes, key economic risks remain with the producers, while the regulation allows for contracts for difference (EHB, ETS). • High competition and administrative burden of the EHB and IF grants risk that producers and users relocate to non-EU countries	• IRA tax credits do not include criteria related to cost efficiency or the funding gap, which leaves targeted use of funding mostly open and risks overfunding. • There is no limit to the funding share and overall public funding under the IRA. • Key economic risks remain with the producers under the IRA tax credits

the EU support systems (C3). To avoid the related market risks, the EU could hedge hydrogen offtakers against price risks when implementing the pending CCfD scheme using the design features proposed in (Richstein et al., 2024).

4.4. Key finding of the comparative assessment

Table 6 summarizes the findings of the assessment over all criteria. It shows the scope and the ex-ante assessment of key deplomentinstruments with reagrd to the criteria by supply chain level. Impacts are evaluated using a qualitative scoring framework (🔴🟡🟢) indicating negative, neutral, or positive effects, respectively.

The comparative assessment reveals that EU policies place strong emphasis on economic efficiency and GHG effectiveness by structurally prioritizing renewable hydrogen, the latter through restricting support under the European Hydrogen Bank to renewable (and since 2025 also electrolytic low-carbon) hydrogen and by limiting demand-side quotas to renewable hydrogen only. By contrast, resilience of hydrogen uptake is addressed more indirectly through EU-wide infrastructure planning, market rules, and demand-side quotas that reduce coordination failures along the value chain but a dedicated demand-side supply scheme is lacking. The US largely relies on strong domestic production and consumption incentives and regional hydrogen hubs. The absence of explicit mechanisms to align supply, demand, and infrastructure at the system level and to phase-out the incentivized production of fossil-based hydrogen results in drawbacks with regard to resilience and GHG effectiveness in the US. Economic efficiency emerges as the weakest dimension in the US: Easy-to-access PTCs have proven effective in mobilizing investment rapidly, but their open-ended design, lack of volume or budget caps, and weak linkage to funding gaps risk persistent overcompensation as costs decline.

4.5. Analysis to validate the ex-ante assessment

To assess the effects of policy measures on the actual ramp-up of hydrogen supply and infrastructure, developments in the IEA Hydrogen Project Database (cf (IEA, nda).) were analyzed. The analysis of advanced-stage projects, defined as those with a final investment decision (FID), under construction, in operation or in the demonstration (DEMO) phase, reveals differences across regions and technologies, see Fig. 2. An analysis of all the projects announced to be in operation by 2030 can be found in the supplementary material.

In the EU, electrolytic hydrogen capacity declined between 2022 and 2023, primarily due to a drop in the number of projects at the FID and construction phases. While some of these projects progressed to the DEMO phase, others were cancelled, resulting in a net decrease. In contrast, a significant increase in electrolytic capacity at the FID/construction stage was observed in 2024 (+49%), indicating that the support system is beginning to trigger tangible investment decisions and project execution.

Advanced-stage fossil-based hydrogen projects with CCUS exhibit a more consistent growth trajectory in the EU. Following moderate overall growth across advanced stages in 2023 (+49.8%), fossil CCUS capacity at the FID/construction stage increased sharply in 2024 (more than tenfold), and continued to rise in 2025 (+43%). This indicates sustained investor confidence in fossil-based low-carbon hydrogen pathways, which is likely linked to greater clarity about the regulation due to the adoption of the gas market package and the low-carbon delegated act. Still, the share of electrolytic hydrogen in advanced-stage projects is about twice as high.

In the US, the capacity of advanced-stage electrolytic hydrogen projects expanded rapidly and relatively steadily between 2022 and 2024. Although a decline was observed in 2025 (-26.7%), the overall pattern indicates a faster scaling of electrolytic projects into advanced stages in the US than in the EU. Strong growth in 2023 (+73.7%) was primarily driven by an increase in the number of projects reaching the FID and construction phases. As in the EU, the contraction in advanced-stage capacity in 2025 was largely due to a reduction in FID/construction projects: While some projects advanced to the DEMO phase, many others were cancelled. Regarding fossil-based hydrogen with CCUS in the United States, capacity at the FID/construction stage more than doubled between 2023 and 2024 (+123%), indicating strong incentives for fossil-based low-carbon hydrogen deployment. However, this expansion was reversed between 2024 and 2025, with capacity falling below 2023 levels. Beyond the downturn observed globally, one potential explanation for this significant decline is the uncertainty surrounding US hydrogen projects following the Trump administration's changes to the IRA. This may have shaken investor confidence and had a negative influence on investment expectations, which underlines the strong impact of the IRA tax credits. However, this decline should not be attributed to policy changes alone. Broader macroeconomic factors, including elevated interest rates, persistent inflationary pressures on capital costs and ongoing supply chain bottlenecks for electrolyzer and CCS equipment, have also likely contributed to the observed contraction. These factors cannot be fully disentangled from the policy effect using the available data (IEA, 2024).

Table 6
Key aspects of EU and US hydrogen support systems across all assessment criteria.

Jurisdiction and supply chain level	Deployment policy instrument	Scope	Resilience of hydrogen uptake	Greenhouse gas effectiveness	Economic efficiency
Hydrogen supply	EHB domestic auctions	Renewable, nuclear	Limited budget	Stringent thresholds, no fossil-based H2	Highly competitive
	Innovation Fund grants	All types of production	No dedicated H2 budget	Selection criterion but no thresholds	Selection criterion but high complexity
Hydrogen demand	RED Quotas	Industry, transport, aviation and maritime	Transparent ramp-up pathways	Stringent thresholds, no fossil-based H2	Market distortion
	Innovation Fund grants	All demand sectors	No dedicated H2 budget,	Selection criterion but no thresholds	Selection criterion but high complexity
Infra-structure	CEF grants	Pipelines	No imports	N/A	Selected based on PCI list
	TEN-E PCIs	Pipelines, terminals	EU-wide coordination, also imports	N/A	Selection based on cost-benefit analysis
Hydrogen supply	IRA production tax credits	All types of production	Uncapped budget	Range of thresholds includes fossil retrofits	Risk of overfunding
	IRA investment tax credits	All types of production	Uncapped budget	No conditions applied	Risk of overfunding
Hydrogen demand	IRA investment tax credits	Road transport, aviation, industry	Uncapped budget	No conditions applied	Risk of overfunding
	BIL hydrogen hubs	All demand sectors	Focus on domestic market creation	No conditions applied	Risk of overfunding
Infra-structure	BIL hydrogen hubs	Pipelines	Only regional coor-dination, no exports	N/A	Risk of overfunding

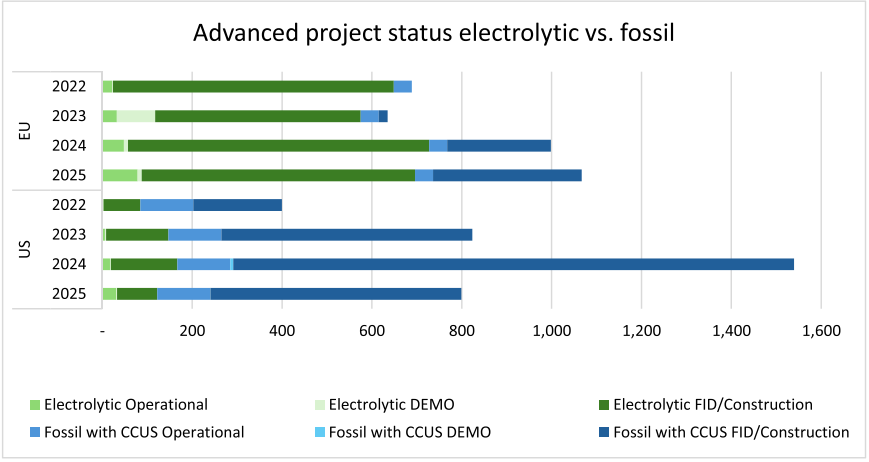


Fig. 2. Advanced project status of electrolytic hydrogen production vs fossil-based hydrogen production with CCUS in the EU and the US.

In summary, the slower increase in advanced projects in the EU until 2024 could be interpreted validation of the negative influence on market uptake expected in Section 4.1 due to the greater complexity of the EHB and the other EU support schemes compared to IRA tax credits. However, in terms of absolute capacity, advanced stage projects in the EU still achieve a similar level, even though the EHB support is limited to electrolytic hydrogen. This means that there is no clear evidence that the administrative burden is prohibitive for creating a domestic market in the EU.

Recalling that fossil-based hydrogen projects in the US will reach only the lower emissions threshold of the IRA and thus receive less funding, their high share suggests that these lower support levels are sufficient for retrofitting existing fossil-based hydrogen production with CCS. This validates the ex-ante assessment that the low ambition of the

GHG thresholds for such projects comes with the risk of a potential carbon lock-in, being not in line with the US long-term GHG neutrality objective. In the EU, the role of fossil-based low-carbon hydrogen remains subordinate to electrolytic hydrogen as expected in the ex-ante assessment, which reduces the risk of a carbon lock-in.

With regard to hydrogen infrastructure, the EU experienced a strong increase in the number of planned pipelines from 119 to 173 between 2024 and 2025, with 7189.2 km of newly built pipelines and 4615.2 km of repurposed pipelines. In the US, there are only two planned hydrogen pipelines according to the 2025 database, with a total length of 794 km compared to one pipeline of 370 km in 2024. This validates the ex-ante findings that the EU support system underpins the market uptake with the necessary infrastructure development, while this is not the case in the US. This raises doubts about the resilience of market creation in the US.

The results of the EHB domestic hydrogen auctions can be used to shed some light on the ex-ante assessment of the EU support system with regard to economic efficiency, again comparing this to the provisions of the US IRA. The EHB's first auction round attracted 132 applications and awarded a price premium of €0.37 – 0.48 per kg H_2 to projects producing up to 1.5 million tonnes of renewable hydrogen in the first ten years of operation. The second auction round attracted 61 applications and awarded a premium of €0.33 – 0.85[2] per kg H_2 to 18 projects producing renewable hydrogen, and a premium of €0.45 – 1.88 per kg H_2 to three additional projects under the maritime window. These premiums can be considered moderate when compared to the current market prices of about €3 per kg of conventional hydrogen in the EU, or even relatively low when compared to the expected cost gap in 2030 between renewable and conventional hydrogen given in the literature.

Compared to the IRA support of $0.45 – 3.0 per kg H_2 (corresponding to €0.4 – 2.7 based on the average exchange rate in 2025), the EHB is at the lower end of this range or even below in absolute terms, while domestic RFNBO production can be expected to meet the US GHG threshold for a tax credit of $1.0 – 3.0 per kg H_2. This is validation that the competitive auction mechanism of the EU leads to lower funding costs than the US support system. However, the decreasing number of applications for EHB support suggests that only a limited set of projects can become viable with the low level of premiums observed. Given the large number of project announcements, this is most likely due to a lack of demand, which would align with the ex-ante identified implementation gap concerning demand-side schemes.

5. Conclusion

The rapid uptake of hydrogen, which is required to decarbonize hard-to-abate sectors, faces multiple barriers, in particular a three-sided chicken-and-egg problem: supply and demand ramp-up are interdependent, as demand cannot rise without sufficient supply, and supply cannot be expanded without sufficient demand. Furthermore, spatially distributed trade that connects hydrogen suppliers and offtakers depends on the timely expansion of transport infrastructure. Currently, the EU uses demand-side quotas and provides funding only via competitive schemes due to its limited fiscal income, while the US emphasizes local manufacturing and incentivizes the domestic market by making uncapped funding accessible to producers and various user groups.

Due to the market and system failures, a mix of support policies is required that addresses the hydrogen uptake in a comprehensive manner, considering the trade-offs between *GHG effectiveness, economic efficiency, and the resilience of hydrogen uptake*. Criteria were developed for an ex-ante assessment of the instrument mixes in national hydrogen strategies along the whole supply chain (supply, demand and infrastructure) and addressing not only electrolytic but also fossil-based low-emissions hydrogen. This represents an important expansion of the assessment frameworks available in the literature before. The criteria were applied to the EU and the US support systems due to their leading role and diverging approaches. The ex-ante findings were validated based on recent market dynamics as far as already possible given the infancy of the market, thereby going beyond former ex-ante analyses and enabling a more robust derivation of policy implications.

The ex-ante assessment reveals that the EU has a stringent framework with regard to GHG effectiveness and economic efficiency but that the hydrogen uptake may suffer from insufficient and fragmented funding. While the auctions for domestic hydrogen production were successful in delivering relatively low-cost bids, regulatory burdens may hamper the ramp-up of manufacturing capacities in the EU, and could shift new investment to other jurisdictions. This could make the EU's hydrogen sector more dependent on global markets and thus less resilient to market distortions, calling for additional policy safeguards. Introducing mechanisms that favor domestic manufacturing in the IF grants and the EHB's domestic leg could increase resilience to market distortions, though likely at the cost of reduced short-term cost efficiency.

The combination of the high standards for renewable and low-carbon hydrogen production, which exclude only partially abated fossil hydrogen production, and the quotas for renewable hydrogen could drive the phase-out of fossil-based hydrogen in the EU. The EU should therefore consider an economy-wide expansion of the quotas for renewable fuels in the RED, in accordance with those in the FuelEU Maritime and Aviation Regulations, and their steady increase to 100% until 2050.

Current market dynamics suggest that the implementation gap with respect to a funding scheme for hard-to-abate sectors risks the required transition to hydrogen-based fuels in these sectors not being viable. Here, the EU could benefit from the experiences with national schemes developed in its Member States, in particular how to hedge hydrogen price risks without favoring hydrogen over direct electrification as done in the German CCfD scheme (Richstein et al., 2024). The EU could reduce coordination failures and foster demand uptake, which is more resilient, GHG-effective and efficient by implementing a similar CCfD scheme.

The ex-ante assessment revealed that, until recently, the US had a looser governance approach with smaller burdens but also more risks in terms of GHG effectiveness and economic efficiency. Before the rollback by the second Trump administration, the IRA tax credits were open to any applicant and offered bonuses linked to the degree of emission reduction and local production. This made it easy for potential producers to access funds but risked overfunding them once the need for funding declined due to upscaling and technological learning. The availability of support for only partially abated fossil-based hydrogen meant that market uptake was likely to include substantial fossil investment and represented a significant risk to GHG effectiveness and economic efficiency. To address the corresponding market failures and increase the GHG effectiveness of its support, the US would need to adjust the thresholds so that fossil-based hydrogen production with only partial CCS is no longer eligible. The recently adopted phaseout of the H_2 PTCs while retaining CCUS credits, however, suggests an adverse shift in the US support system. Nonetheless, recent market dynamics show also a decline in fossil-based low-emissions hydrogen project, indicating uncertainty about the future hydrogen uptake in the US as a whole.

The absence of planned transport and export infrastructure as well as the lack of a strong framework to promote it indicates that the US approach may lead to a more decentralized model of hydrogen production and use. To avoid potential coordination failures and increase resilience and economic efficiency, the US should consider introducing a policy to monitor and react to unintended market dynamics, such as a slower-than-expected uptake of local demand without options to deliver

[2] The originally selected projects had a bid range of €0.2 – 0.6 per kg H_2, but several of them withdrew their bid during grant preparation, cf. https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/calls-proposals/if24-auction_en

to other markets.

An important aspect of hydrogen market uptake beyond energy and climate policy-related aspects is the industrial policy perspective, in particular, the creation of local economic value and jobs. This aspect has only been mentioned under the resilience criterion. As indicated above, the US has put more effort into creating such local value, even ensuring that regions with structural deficits will benefit. This aspect could be strengthened in the EU when implementing its Clean Industrial Deal. Future research should also address the impact on local value creation of import tariffs like those recently introduced by the Trump administration. Another issue beyond the scope of this article is how hydrogen uptake in the EU and the US will drive and interact with the development of global markets. The potentially high viability of production and the willingness to pay in other countries are likely to have strong impacts on EU and US markets. Future research should take this into consideration.

A.1 Nomenclature

Abbreviation	Meaning
AEPC	Advanced Energy Project Credit
BIL	Bipartisan Infrastructure Law
CCfD(s)	Carbon Contract(s) for Difference
CCS	Carbon Capture and Storage
COSTC	Carbon Oxide Sequestration Tax Credit
CEF	Connecting Europe Facility
CO_2	Carbon dioxide
CO_2 eq	Carbon dioxide equivalent
DEMO	Demonstration phase
EC	European Commission
EHB	European Hydrogen Bank
EU	European Union
EU ETS	European Union Emissions Trading System
FCEV(s)	Fuel Cell Electric Vehicle(s)
FID	Final Investment Decision
GHG	Greenhouse Gas(es)
GW	Gigawatt
H_2	Hydrogen
H_2/y	Hydrogen per year
IEA	International Energy Agency
IF	Innovation Fund
IPCC	Intergovernmental Panel on Climate Change
IPCEI	Important Project of Common European Interest
IRA	Inflation Reduction Act
mmBTU	million British thermal units
NZIA	Net Zero Industry Act
OBBBA	One Big Beautiful Bill Act
PCI	Project of Common Interest
PTC	Production Tax Credit
RED	Renewable Energy Directive
RES	Renewable Energy Sources
RES-E	Renewable Electricity
RFNBO(s)	Renewable Fuel(s) of Non-Biological Origin
TEN-E	Trans-European Networks for Energy
US	United States (of America)

CRediT authorship contribution statement

Jakob Wachsmuth: Writing – original draft, Validation, Methodology, Conceptualization. **Rainer Quitzow:** Writing – original draft, Visualization, Data curation, Conceptualization. **Zarah Thiel:** Writing – original draft, Conceptualization. **Laima Eicke:** Investigation, Data curation. **Ellen Österlein:** Writing – original draft, Investigation, Data curation. **Yana Zabanova:** Writing – original draft, Investigation, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.egyr.2026.109778.

Data availability

Data will be made available on request.

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